A STUDY OF THE EFFECTS OF LONG-TERM GROUND AND FLIGHT ENVIRONMENT EXPOSURE ON THE BEHAVIOR OF GRAPHITE-EPOXY SPOILERS

By Robert L. Stoecklin

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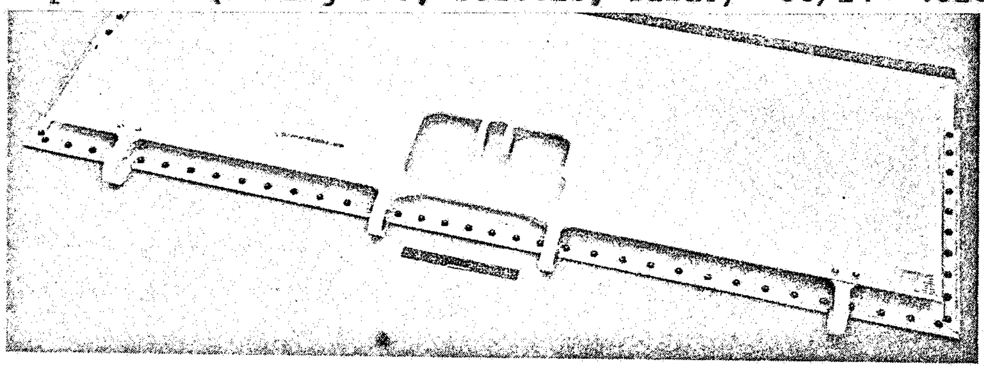

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16. Abstract

This quarterly progress report is prepared in compliance with the requirements of contract NAS1-11668 and covers work performed from contract initiation (June 20, 1972) through September 30, 1972. Task I of this contract is under way and consists of tooling and procurement activities required to implement the production run of 114 Boeing-designed graphite flight spoilers for the 737 airplane. The task II effort, which will include design and fabrication of an advanced-design, all-composite spoiler, will begin in the next quarterly period. Flight spoilers from both task I and task II will be flown on commercial 737s for a period of 5 years to gather data on the environmental durability of graphite-epoxy material systems.

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By Robert L. Stoecklin
The Boeing Company

SUMMARY AND PROGRAM STATUS

The first quarter activities have been devoted primarily to screening and evaluating graphite material candidates, preparing specifications for fabrication processing and quality control of graphite materials, and designing and fabricating tooling.

The screening and evaluation of graphite material candidates is presented in the "Design" section, with tabular results of the properties and other qualities of each of the six competing vendor products. The data compiled are considered to be sufficiently conclusive to make the appropriate recommendations to NASA to select three graphite suppliers.

The tooling design and fabrication effort is proceeding on schedule as shown in the "Production" section.

INTRODUCTION

Considerable effort has been expended in recent years to explore the potential of composite materials as a means of increasing structural efficiency and fatigue life of aircraft structure. Numerous efforts have been undertaken to design and fabricate representative portions of aircraft structures, with the method of substantiation primarily characterized as static testing. Relatively modest efforts have been expended to gather meaningful fatigue data while virtually no information is available to evaluate the ability of composite structure to resist the various environmental exposures encountered in regular commercial airline service. It is to this latter environmental exposure problem that this program is being addressed.

The Boeing Company has for several years been engaged in a developmental program to adapt the technology of advanced-composite materials to production airplane components. This program has progressed to the point where specific airplane components have been fabricated, FAA approval has been obtained, and units have been introduced into service test on commercial aircraft. Two boron-epoxy foreflaps are currently being flown on a 707 aircraft by Northwest Airlines. In addition, two graphite-epoxy flight spoilers have been installed and are currently in service on a Western Airlines 737 (fig. 1). It is these Boeing-designed spoilers, in particular, which offer an exceptional opportunity to gain extensive service exposure and experience. Though important functionally, they are not critical to the safety of the aircraft. The installation positions selected for the spoilers (fig. 2) are in the minimum lightning exposure zone (fig. 3) to minimize the potential problem associated with lightning strikes.

Each 12-lb spoiler provides a sizable exposure area (15.8 sq ft). Each unit is easily installed and readily removable for inspection or replacement. This provides the opportunity for periodic laboratory inspection and evaluation. Each composite spoiler can be individually replaced with an aluminum spoiler should the situation warrant.

The model 737 is an excellent aircraft to provide test exposure. Each aircraft is typically accumulating approximately 3000 flight-hours per year. Flight times are relatively short, providing maximum environmental cycling. The choice of operational environment is almost unlimited. Approximately 300 of these aircraft are in service over a worldwide route system.

Under this contract, a limited production run of 114 task I and 11 task II spoilers will be produced for laboratory testing and service evaluation deployment. Four spoilers will be installed on each of 27 aircraft representing five major airlines operating in different environmental circumstances. These units will be monitored under actual load and environmental conditions for a period of 5 years. Periodic removal of selected units will be accomplished to evaluate any material degradation as a function of time. Task II spoilers will be phased into the evaluation program as additional installations as well as replacements for task I spoilers removed for evaluation and testing.

DESIGN

MATERIAL SCREENING

In accordance with contract NAS1-11668, a materials screening program was conducted by the Structures Technology—Materials organization to select three graphite-epoxy systems from several epoxy matrixes and graphite reinforcements that are commercially available. The screening program sequence of events was as follows:

- Contact epoxy-graphite vendors and establish quantity of prepreg required and establish delivery date.
- Receive prepreg and fabricate test laminates.
- Prepare test specimens and condition specimens as required.
- Coordinate with manufacturing to evaluate prepreg for tape laying machine adaptability.
- Conduct tests for mechanical properties and laminate and prepreg physical properties.
- Reduce data and summarize findings.
- Make recommendations for selection of three graphite-epoxy systems.

The suppliers contacted are listed in table 1, which also lists the other suppliers that submitted material in time to be evaluated in the screening program.

As graphite-epoxy material was received, it was inspected visually for defects and general quality. Unidirectional and crossplied laminates were layed up and cured to provide tensile, compression, and short-beam shear-test specimens, as shown in figure 3.

Each supplier specified cure cycles for either autoclave or positive-pressure cycles and provided layup instructions for bleeder and vacuum bagging application. The laminate layup is shown in figure 4. The cure cycles, shown in figures 5 through 10, were followed closely.

Test specimens were machined from the cured laminates after fiberglass tabs were bonded to both surfaces at each end. The specimen configurations are as shown in figures 11 through 13. Each specimen was permanently identified according to vendor, laminate orientation, load direction, and specimen number. Test specimen conditioning consisted of the following:

- As laminated; no conditioning
- Elevated temperature; exposed to 160° F environment for a 1/2 hr and tested at 160° F
- Wet; exposure to humid environment of 140° F and 100% relative humidity for periods of 30 and 42 days, tested wet at room temperature.

TABLE 1.—GRAPHITE MATERIAL SOURCES SOUGHT

Supplier	Product description	Fiber		Remarks
		Type	Form	
E. I. Du Pont, Industrial Products Division	Corlar 5143	AS Collimated tape	Sheet t = 0.006 in.	—
Fothergil and Harvey, Limited Composite Materials Division	Carboform; Shell 828/DDM/ $BF_3$400 resin	AS	3 in. tape t = 0.010 in.	—
Great Lakes Carbon Corporation	Fortafil 4-T; X934 resin	AS	3 in. tape t = 0.005 in.	—
Hercules Incorporated, Systems Group	Hercules X3501	AS	3 in. tape t = 0.005 in.	—
Rolls-Royce, Limited	Hyfil type 2742	AS	3 in. tape t = 0.005 in.	Submitted too late to evaluate
Union Carbide Corporation, Carbon Products Division	Thornel 300/2544	AS	3 in. tape t = 0.005 in.	—
Whittaker Corporation Narmco Materials Division	Modulite 5209	AS	3 in. tape t = 0.005 in.	—
U.S. Polymeric Chemicals, Incorporated	E-42-1; Hitron 401 resin	AS	3 in. tape	Did not submit
Fiberite Corporation	Hy-E	AS	3 in. tape	Did not submit

A summary of the observations of prepreg and laminate quality is shown in table 2, which is based on visual observations and problems that occurred during handling. Vendors were requested to supply a product that represented their best "production" material.

Table 3 shows a tabulation of mechanical properties obtained thus far in the test program. Data are not yet available for the areas of the table that are blank. In addition to Boeing test data, typical vendor data are presented for comparison and to establish correlations between vendor and Boeing test data. In addition, prepreg and laminate physical properties are shown. A discussion of the test results follows.

TABLE 2.—OBSERVATIONS ON PREPREG AND LAMINATE QUALITY

Vendor	Prepreg	Laminate
1	Supplied in 4-in.-wide tape. Fiber uniformity good with minimum number of defects.	Quality good.
2	Good uniformity in tack, filament orientation, width control, and resin distribution. Thickness slightly low.	Overall quality was good except that considerable warpage of unidirectional laminates occurred during postcure. Warpage in 0°direction.
3	General quality fair. Defects were marked, but splices were made in such a manner that the splice tape was difficult to see in prepreg. Several areas of fiber separation with gaps up to 1/16 in. were noted. Resin uniformity appeared satisfactory.	Quality poor in that "washboarding" occurred across the width or unidirectional laminates. This condition was minimized in the crossplied laminates.
4	Prepreg supplied in 9- by 60-in. sheet since tape impregnation equipment not operational. First batch quality fair to poor but second batch quality very good. Thickness control poor.	Unidirectional laminates fabricated using first batch, crossplied laminates fabricated using second batch. Unidirectional laminate quality fair and crossplied laminate quality good.
5	Overall quality excellent except that prepreg supplied in 0.008-in. thickness instead of of 0.005 in.	Laminate quality excellent but used half the number of plies per laminate as those of vendors 1, 2, 3, 4, and 6 because of prepreg thickness. This resulted in laminates being somewhat thin.
6	General quality very poor with considerable filament separation and foldover. Resin distribution poor with bands of high and low resin content occurring across tape width.	Laminate quality poor with considerable "washboarding" occurring in both unidirectional and crossplied laminates.

TABLE 3.–MECAHNICAL PROPERTIES DATA SUMMARY

Test Property	Vendor											
	1		2		3		4		5		6	
	Boeing data	Vendor data	Boeing data	Vendor data	Boeing data	Vendor data	Boeing data	Vendor data	Boeing data	Vendor data	Boeing data	Vendor data
Compression ultimate												
0° at RT	129.0	160.0	124.6	172.0	125.5		149.3	142.0	103.7	200.0	157.4	150.0
0° at 160° F												
0° at RT, 30 days 140° F and 100% RH	112.2	108.5										
0° at 160° F, 30 days 140° F and 100% RH												
0° crossplied at RT	76.0		53.5		65.5		64.8		59.7		49.2	
Compression modulus												
0° at RT	19.2	17.0	21.5	22.5	14.5				18.7	20.0		
0° crossplied at RT	7.2		7.1		5.9				6.0			
Tensile ultimate												
0° at RT	161.0	170.0	194.3	174.0	190.2	202.0	166.7	175.0	211.2	200.0	121.5	170.0
0° at 160° F	177.1		206.2		180.0		172.5		226.8		121.2	
90° at RT	5.3		2.6		5.2		4.9		3.0		3.1	
90° at 160° F	4.5		4.7		4.1		4.1		3.6		3.5	
0° crossplied at RT	72.0		64.1		56.2		60.8		60.8		47.2	
Tensile modulus												
0° at RT	17.0	18.0	23.7	20.5	18.1	15.5	22.8	17.5	22.5	18.0	24.1	19.0
0° at 160° F	19.1		25.9		19.7		22.8		26.5		27.2	
90° at RT	1.56		2.07		1.82		1.41		1.71		2.52	
90° at 160° F	1.24		1.73		1.75		1.31		1.54		2.29	
0° crossplied at RT	5.4		9.1		7.4		7.8		9.0		11.1	
Short-beam shear[a]												
0° at RT	11.9	14.0	7.9	15.0	13.5	13.6	10.2	12.3	10.1	12.5	7.8	16.0
0° at 160° F	9.7		6.9		11.0		8.4		7.6		7.6	
0° at RT, 30 days 140° F and 100% RH	10.0		6.4									
% fiber volume (laminate)	54.0	62–64	68.0	≈60.0	55.0	56.0	64.0	56.-60.	64.5	65.0	61.0	60.0
% resin solids (prepreg)		≈40.0		≈40.0		≈38.0		≈38.0		≈43.0		≈39.0
Cured laminate thickness per ply	0.005		0.004		0.0055		0.0065		0.0075		0.005	0.0054

[a]Boeing data span-to-depth ratio 5:1; vendor data span-to-depth ratio 4:1.

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Compression Properties

The Celanese method was followed for compression specimen configuration and testing. Tested and untested specimens (with and without strain gages) are shown in figures 14 through 17, and specimens installed in the Celanese test fixture are shown in figures 18 and 19. Data were not complete for humidity and elevated-temperature exposure. However, the compression values obtained at ambient temperatures are shown. The data indicate a low compression strength. On examination of the test specimens and stress analysis, the conclusion is that the specimen thickness is such that the critical buckling stress may have been exceeded.

The effect of specimen thickness variation will be verified by additional tests in that specimens will be fabricated with a thickness of approximately 0.125 in. Specimens machined from panels exhibiting a "washboard" condition are extremely difficult to evaluate.

Tensile Properties

Figure 20 shows unidirectional and crossply oriented test specimens in the failed condition. It is felt that an improvement in ultimate strength and test consistency will be obtained by changing the specimen configuration to a maximum thickness of 0.040 in.

The above change in specimen configuration will primarily affect the strength of the unidirectional laminate loaded at 0°. Evaluation of test results at room temperature and 160° F led to the conclusion that some uneven fiber loading may have occurred in the specimen at room temperature that did not occur at 160° F when the resin softened slightly. This effect resulted in a strength increase of approximately 3% to 8% at 160° F. The strength increase at 160° F may be somewhat typical, however, as indicated by a review of test results from technical literature. The thickness restriction and its effect on strength will be verified by additional tests.

Short Beam Shear

The shear data show Boeing results to be consistently lower than vendor data. This could be attributed to a difference in the span-to-depth ratio. Boeing tested at a 5:1 ratio and the vendors used 4:1. This will be explored through further testing.

Physical Properties

The prepreg data are not yet available. The volume fraction of the laminate has been evaluated and varies from a low of 54% for vendor 1 to a high of 68% for vendor 2. Adjustments will be made on the three suppliers' materials in the production process to ensure uniformity of fiber volume in the finished product.

At completion of the preliminary screening program, some test discrepancies will be checked by additional tests. A complete profile of physical, chemical, and mechanical properties will be obtained on the three materials selected for fabrication of the production spoiler.

QUALITY CONTROL

Quality Control Research and Development effort has been devoted to development of nondestructive testing parameters for use in fabricating the task I production spoilers. Close coordination has been maintained with engineering and manufacturing to aid in preparing the material and processing specifications.

The major effort has been to establish the proper nondestructive testing parameters. To this end, the following have been accomplished:

- Numerous composite test specimens have been evaluated nondestructively to aid in technique optimization. The techniques and instrumentation used include water-column-coupled, ultrasonic, through transmission; Sondication (air-coupled ultrasonic); Fokker bond tester; and harmonic bond tester.
- Reference standards are being developed for instrumentation that will provide a common base for each inspection technique.
- The Boeing-developed C-scan recorder is a multicolored recorder that provides complete NDT information in a single recording. This device allows the recording of each of 10 discrete sound attenuation levels through the entire range of ultrasonic signals. Each of 10 colors represents one interval. Work is progressing toward improving the speed of the C-scan recorder because it is relatively slow when compared to the conventional black-and-white C-scan recorder (one level).
- Inspection personnel are being trained for production use of the NDT facility.
- A draft of the NDT procedure is being prepared and will be available to manufacturing prior to first-article inspection.

ENGINEERING DESIGN

The engineering drawings prepared for the Boeing independent research effort are in the process of being redrawn and modified to reflect current process and material requirements applicable to task I of the NASA contract. The drawings will also contain minor design modifications that should enhance spoiler performance without any degradation of the values required for certification. Figure 21 shows the relationships of the essential elements of the spoiler.

The redrawing will afford an opportunity to update dash number assignment, eliminate other experimental components, and afford the manufacturing section simpler and more efficient planning and recordkeeping tasks.

PROCUREMENT

GRAPHITE MATERIAL

Since the first quarterly activity is devoted to screening and evaluating the graphite composite materials of several candidate suppliers, no activity can be undertaken toward purchasing the required graphite tape until the evaluation procedure has been completed and the resulting selections made concurrently between NASA and Boeing.

METAL DETAILS

All aluminum detail components that are common for the task I spoiler and the production 737 spoiler are to be purchased from the current spoiler subcontractor. Negotiations have been concluded and the appropriate purchasing orders placed with the subcontractor to supply these components on a schedule that will support the established production rate.

These components are:

65-49507-9	Center hinge fitting
65-37870-1	End hinge fitting
65-46451-3	Honeycomb core
65-46451-21	Clip
65-45451-22	Clip
65-45451-17	Leading edge channel
65-46451-18	Leading edge channel
10-60545-144	Bearing

PRODUCTION

TOOLING FABRICATION

Design of the production tooling has been a major effort for this reporting period. A total of nine tools have been planned and designed, including a duplicate set of bonding assembly tools, which are required to support autoclave curing of bonded assemblies at a one-per-day production rate.

The tooling designs are conventional production quality and would be capable of supporting sustained production. All tooling will carry the label of, and remain the property of, NASA.

As of September 30, the tooling designs are 100% complete and the tooling fabrication is 75% complete. Completion of all tooling is scheduled for October 20.

SPOILER PRODUCTION

Since tool fabrication is still in progress, the production sequence has not commenced in this period. Figure 22 shows the task I spoiler production schedule, together with the preproduction activities of tooling and procurement necessary prior to production of the first unit. Spoiler production is expected to reach a maximum rate of one per day beginning in March 1973.

SPOILER TESTING

There has been no structural testing or testing associated with the service evaluation program. These activities are scheduled to commence during the third reporting period.

FAA CERTIFICATION

To conduct the service-evaluation portion of this program, FAA approval of both the task I and task II spoilers will be required prior to installation of any units on commercial 737s. Approval has been sought and obtained for the two units currently in service with Western Airlines (see fig. 1), and approval of the task I spoilers is anticipated based on that approval. FAA Western Region has asked for and been provided with a pictorial description of the lightning strike zones on the 737 airplane.

AIRLINE COORDINATION

An integral part of the evaluation program is the scheduling of appropriate vehicles and commercial routes over which the widest possible environmental exposure may be obtained. Consideration was made of high-contamination industrial areas, high-humidity areas, salt-water atmosphere, and conventional domestic routes with the attendant temperature ranges. Within these considerations, an evaluation of service operator problems with structural elements similar to the spoiler also influenced the selection of operators for this program.

Table 4 has been established as the distribution and retrieval plan for spoiler evaluation. The five airlines identified on the plan are:

- United
- Pacific Southwest
- Aloha
- New Zealand
- Lufthansa

All of these operators have been contacted and have expressed interest in participating in the spoiler program. The distribution of spoilers and the number of aiplanes allocated to each airline are being finalized with the individual airlines in continuing negotiations.

GENERAL

PROGRAM SCHEDULE AND PROGRESS

A detailed program schedule has been established for the task I production effort (see fig. 22) in conjunction with the schedule established for the entire spoiler program (fig. 23). Current commitments from suppliers and subcontractors are compatible with this schedule.

TABLE 4.–SPOILER DISTRIBUTION IN SERVICE EVALUATION PROGRAM

Months	Material[a]	Airline 1 (c)	Airline 1 (b)	Airline 2 (c)	Airline 2 (b)	Airline 3 (c)	Airline 3 (b)	Airline 4 (c)	Airline 4 (b)	Airline 5 (c)	Airline 5 (b)	Total units: Material	Total units: Airplanes
12	I	1 2 3	ABCD ABCD ABCD	1 2	ABCD ABCD	1	ABCD	1	ABCD	1 2	ABCD ABCD	36	9
	II	4 5	ABCD ABCD	3 4	ABCD ABCD	2	ABCD	2 3	ABCD ABCD	3 4	ABCD ABCD	36	9
	III	6 7 8	ABCD ABCD ABCD	5	ABCD	3 4	ABCD ABCD	4	ABCD	5 6	ABCD ABCD	36	9
24	I	1 2 3	ABCX ABCD ABCD	1 2	ABCD ABCD	1	ABCD	1	ABCD	1 2	ABCX ABCD	34	9
	II	4 5	ABCD ABCD	3 4	ABCX ABCD	2	ABCD	2 3	ABCX ABCD	3 4	ABCD ABCD	34	9
	III	6 7 8	ABCX ABCD ABCD	5	ABCD	3 4	ABCX ABCD	4	ABCD	5 6	ABCD ABCD	34	9
36	I	1 2 3	ABCX ABCD ABCD	1 2	ABCX ABCD	1	ABCX	1	ABCD	1 2	ABCX ABCD	32	9
	II	4 5	ABCX ABCD	3 4	ABCX ABCD	2	ABCD	2 3	ABCX ABCD	3 4	ABCX ABCD	32	9
	III	6 7 8	ABCX ABCD ABCD	5	ABCX	3 4	ABCX ABCD	4	ABCD	5 6	ABCX ABCD	32	0
48	I	1 2 3	XBCX ABCD ABCD	1 2	ABCX ABCD	1	XBCX	1	ABCD	1 2	ABCX ABCD	30	9
	II	4 5	ABCX ABCD	3 4	XBCX ABCD	2	ABCD	2 3	ABCX ABCD	3 4	XBCX ABCD	30	9
	III	6 7 8	XBCX ABCD ABCD	5	ABCX	3 4	ABCX ABCD	4	ABCD	5 6	XBCX ABCD	30	9
60	I	1 2 3	XBCX ABCD ABCD	1 2	XBCX ABCD	1	XBCX	1	ABCD	1 2	XBCX ABCD	28	9
	II	4 5	XBCX ABCD	3 4	XBCX ABCD	2	ABCD	3 3	XBCX ABCD	3 4	XBCX ABCD	28	9
	III	6 7 8	XBCX ABCD ABCD	5	XBCX	3 4	XBCX ABCD	4	ABCD	5 6	XBCX ABCD	28	9
Totals	Initial units	32		20		16		16		24		108	27
	Units removed	6		6		4		2		6		24	0
Balance at 5 years		26		14		12		14		18		84	27

[a]Three different materials will be used

[b]Airplanes used

[c]Spoiler positions (X indicates spoiler removed)

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MOTION PICTURES

The photography unit is preparing a plan to acquire footage of the various elements of the task I effort. Specific requirements relating to type of film, viewing time, etc., have been coordinated and are being integrated into the planning. A specific format and schedule is being developed.

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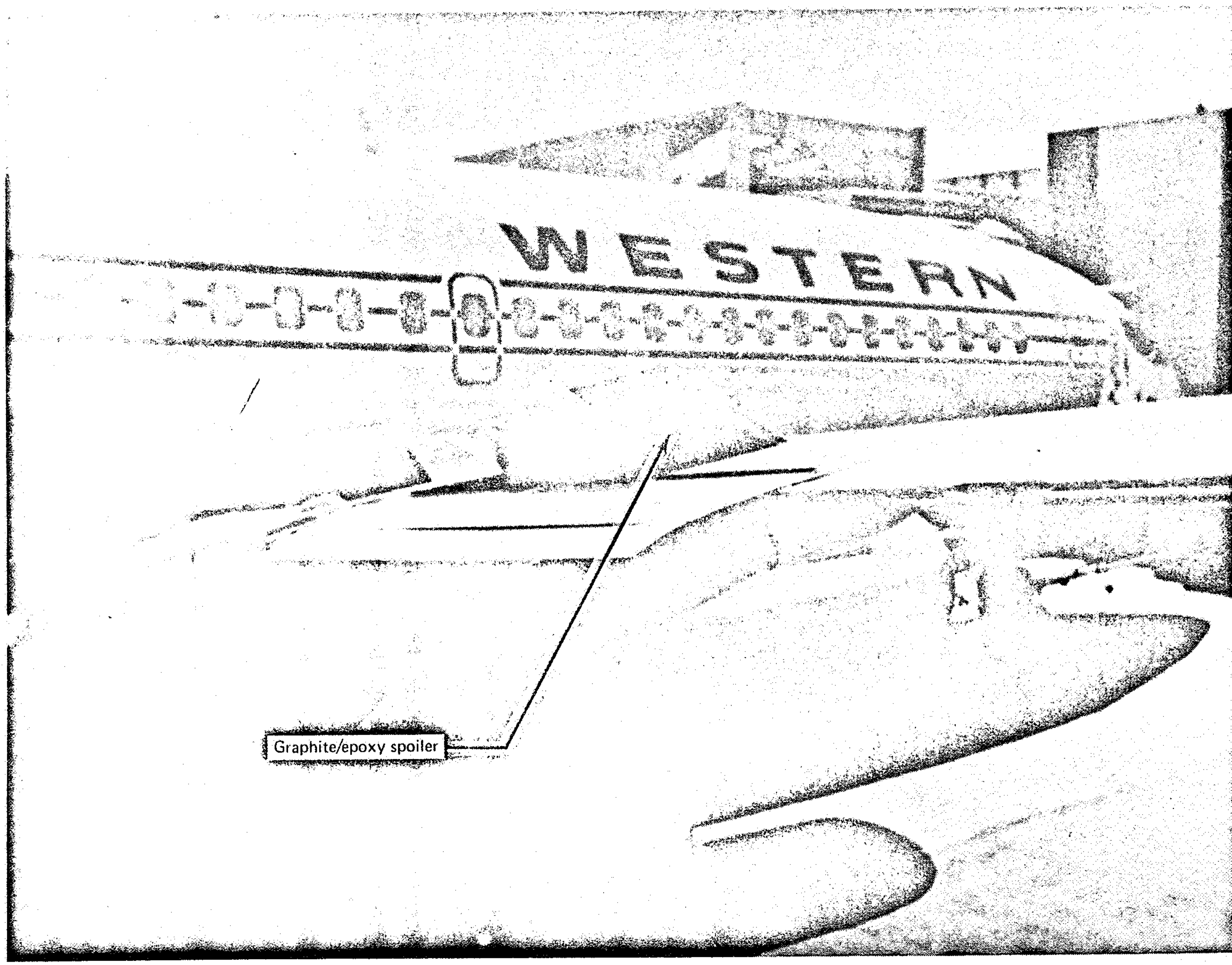

FIGURE 1.—WESTERN AIRLINES SPOILER INSTALLATION

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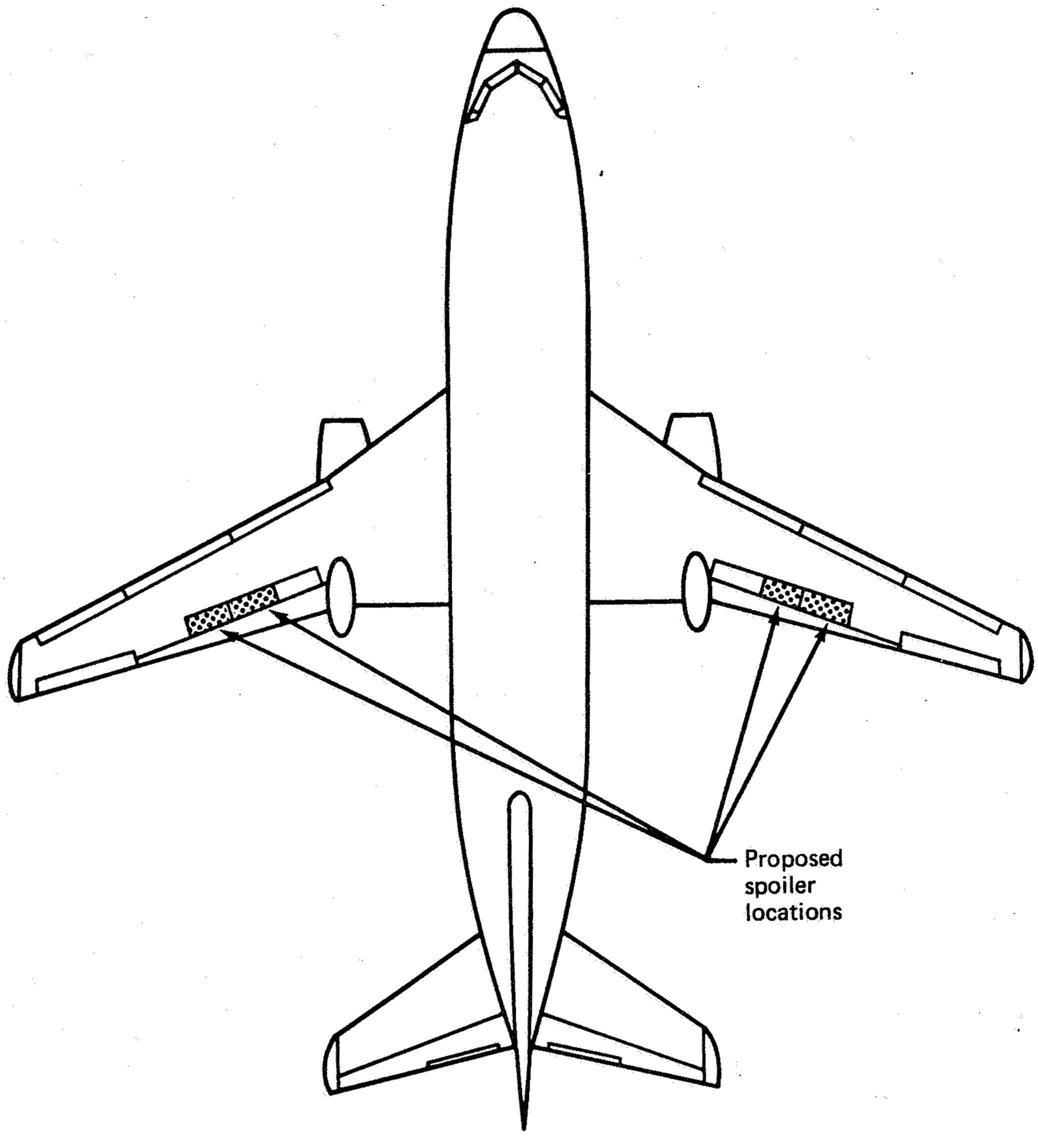
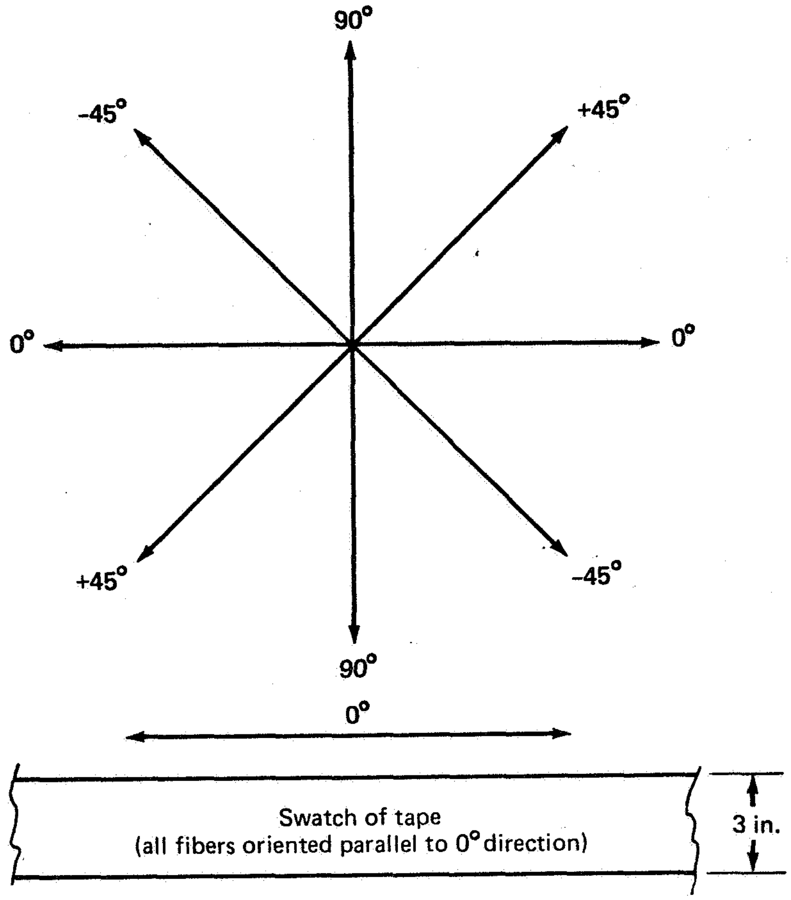


FIGURE 2.—PLAN VIEW OF 737 AIRCRAFT



Unidirectional laminate:
All plies oriented in 0° direction

Crossplied laminate:
Plies oriented in following sequence
$[0°, +45°, -45°, 90°, 90°, -45°, +45°, 0°]_2$

Specimen loading
0° = load applied parallel to 0° direction
90° = load applied perpendicular to 0° direction

FIGURE 3.—TEST SPECIMEN FIBER AND LOADING ORIENTATION

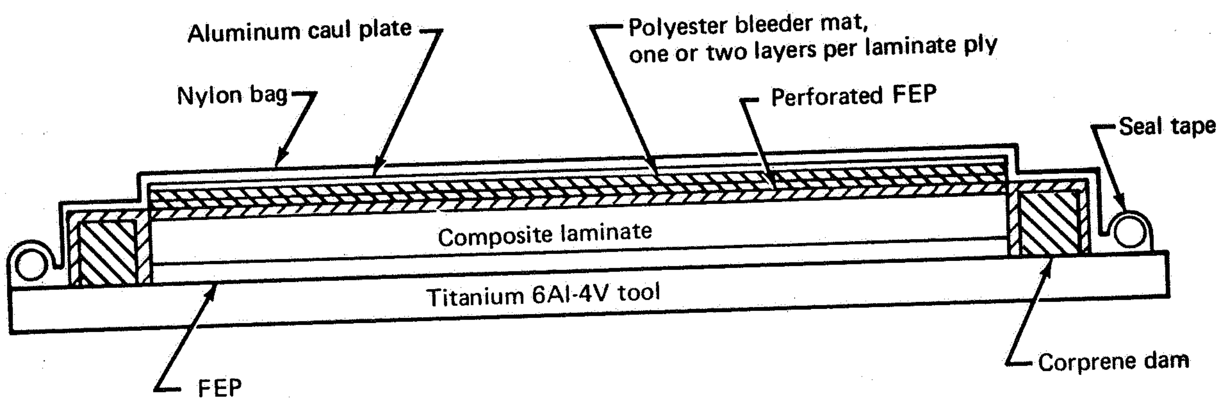


FIGURE 4.—LAMINATE LAYUP

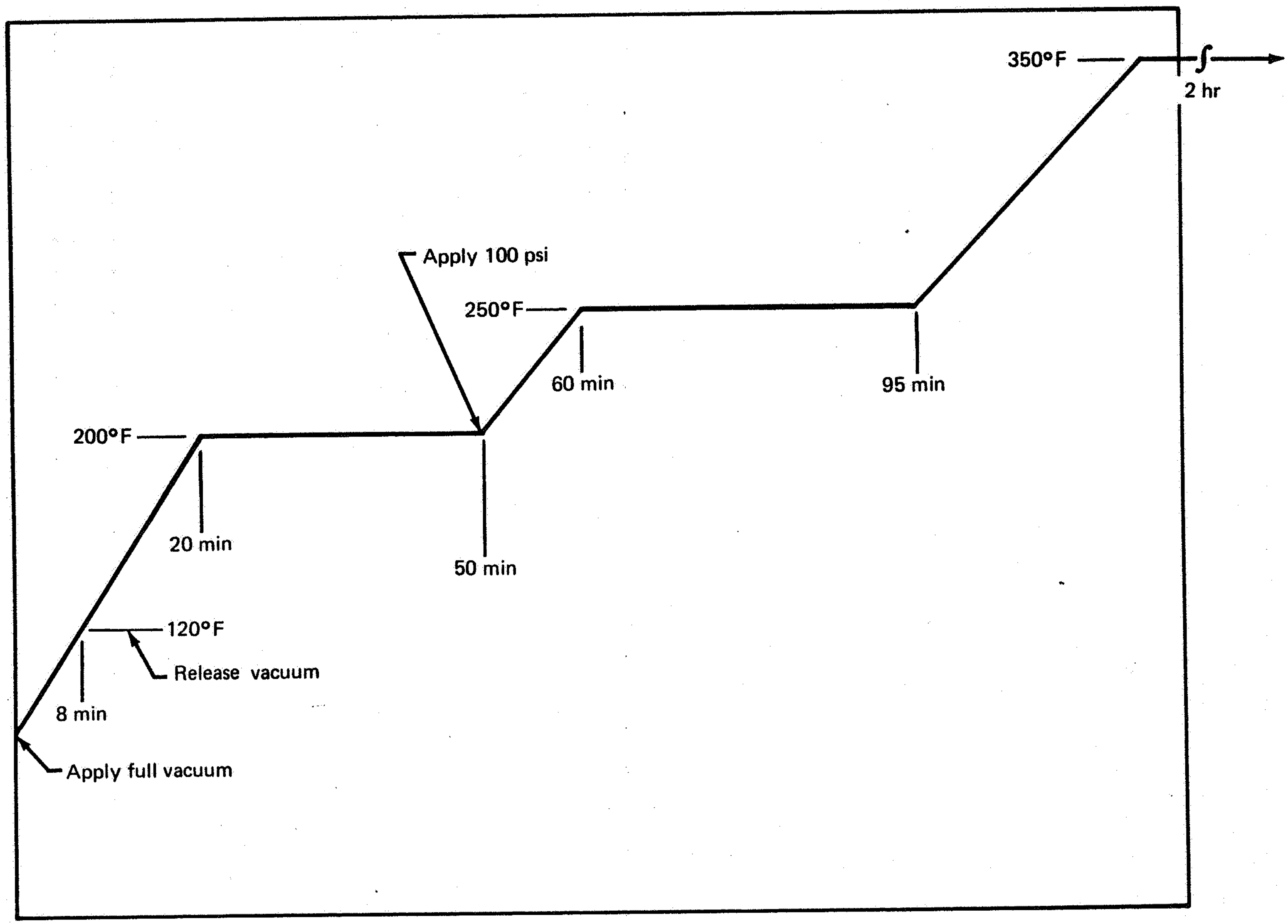


FIGURE 5.—CURE CYCLE—UNION CARBIDE

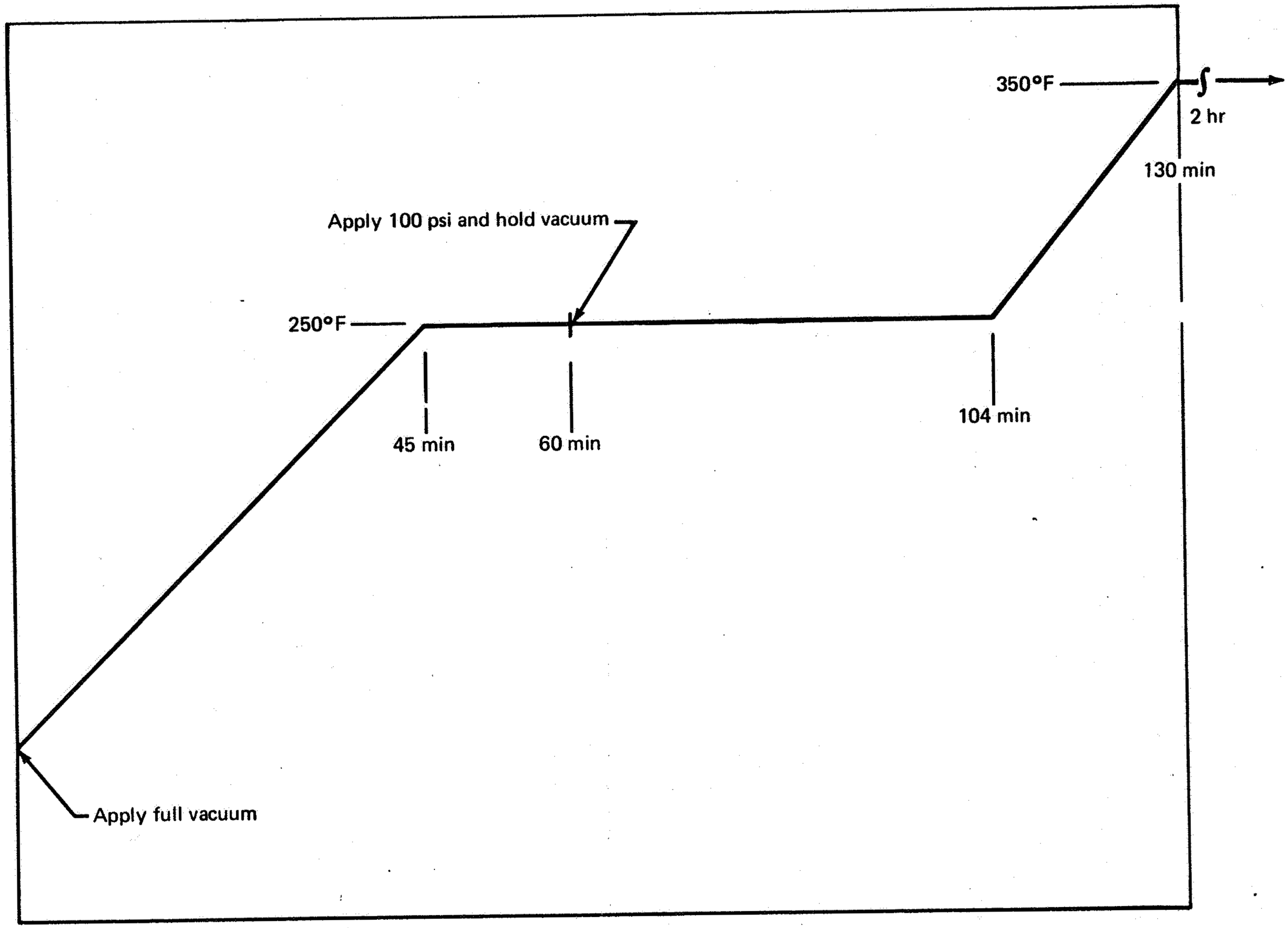


FIGURE 6.—CURE CYCLE—GREAT LAKES CARBON

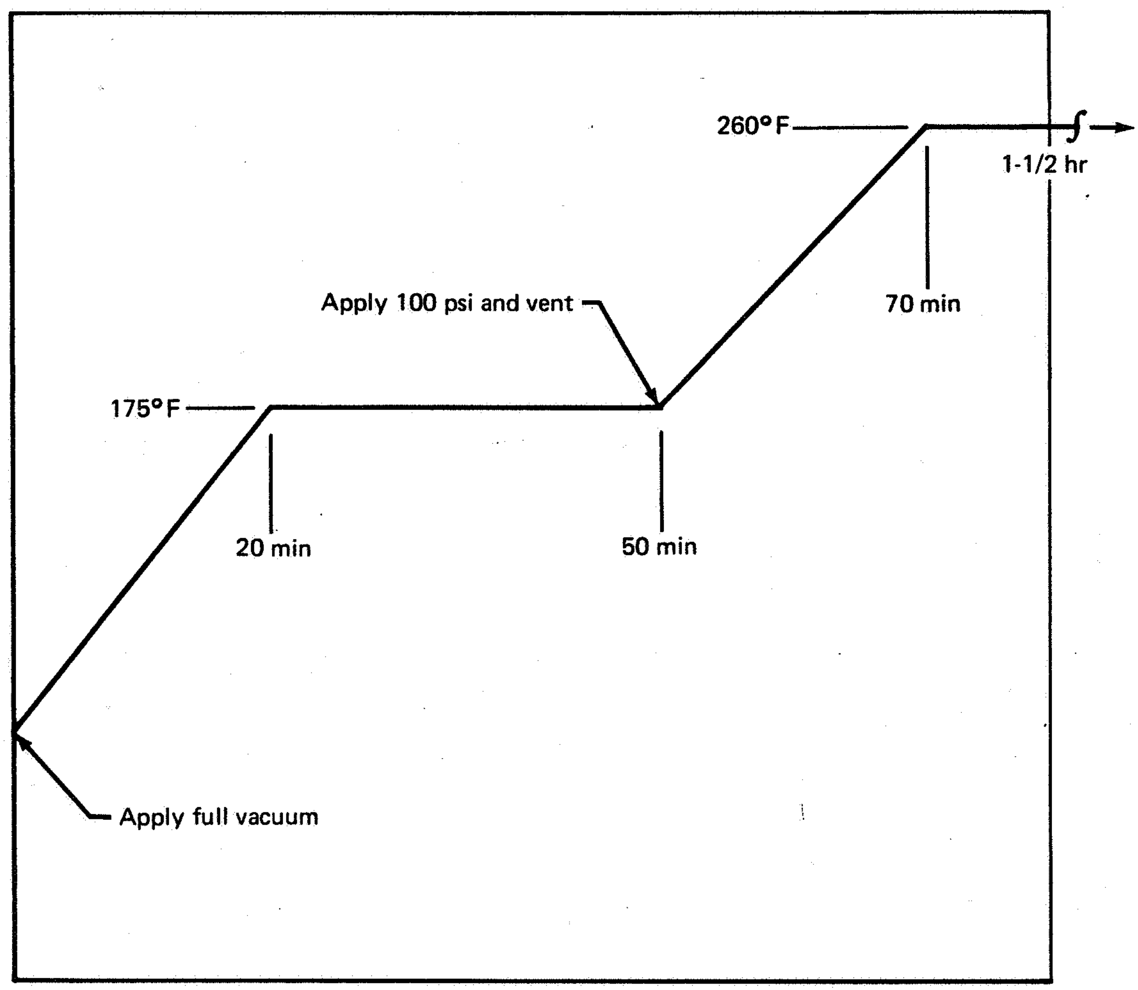


FIGURE 7.—CURE CYCLE—NARMCO

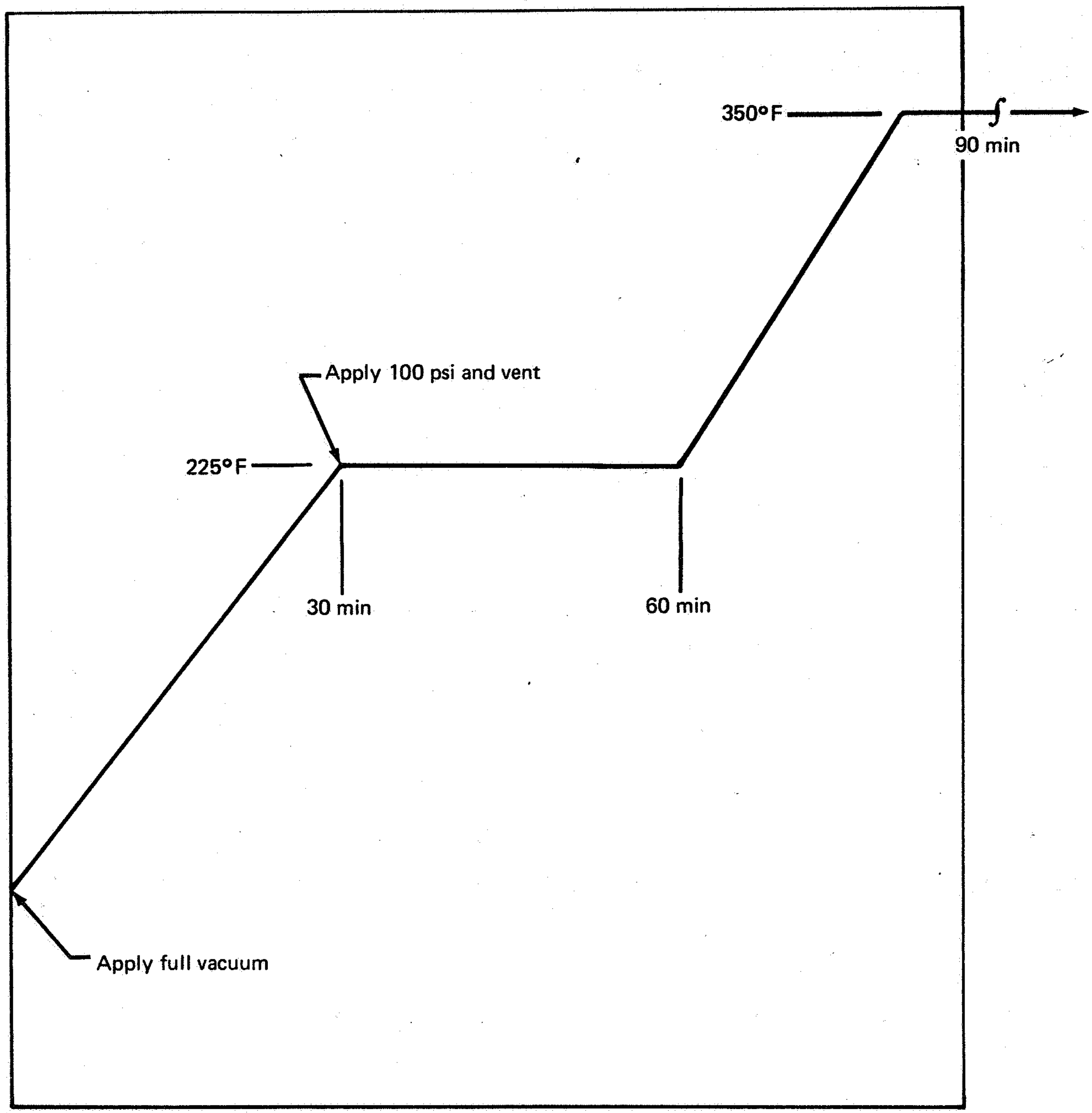


FIGURE 8.—CURE CYCLE—DU PONT

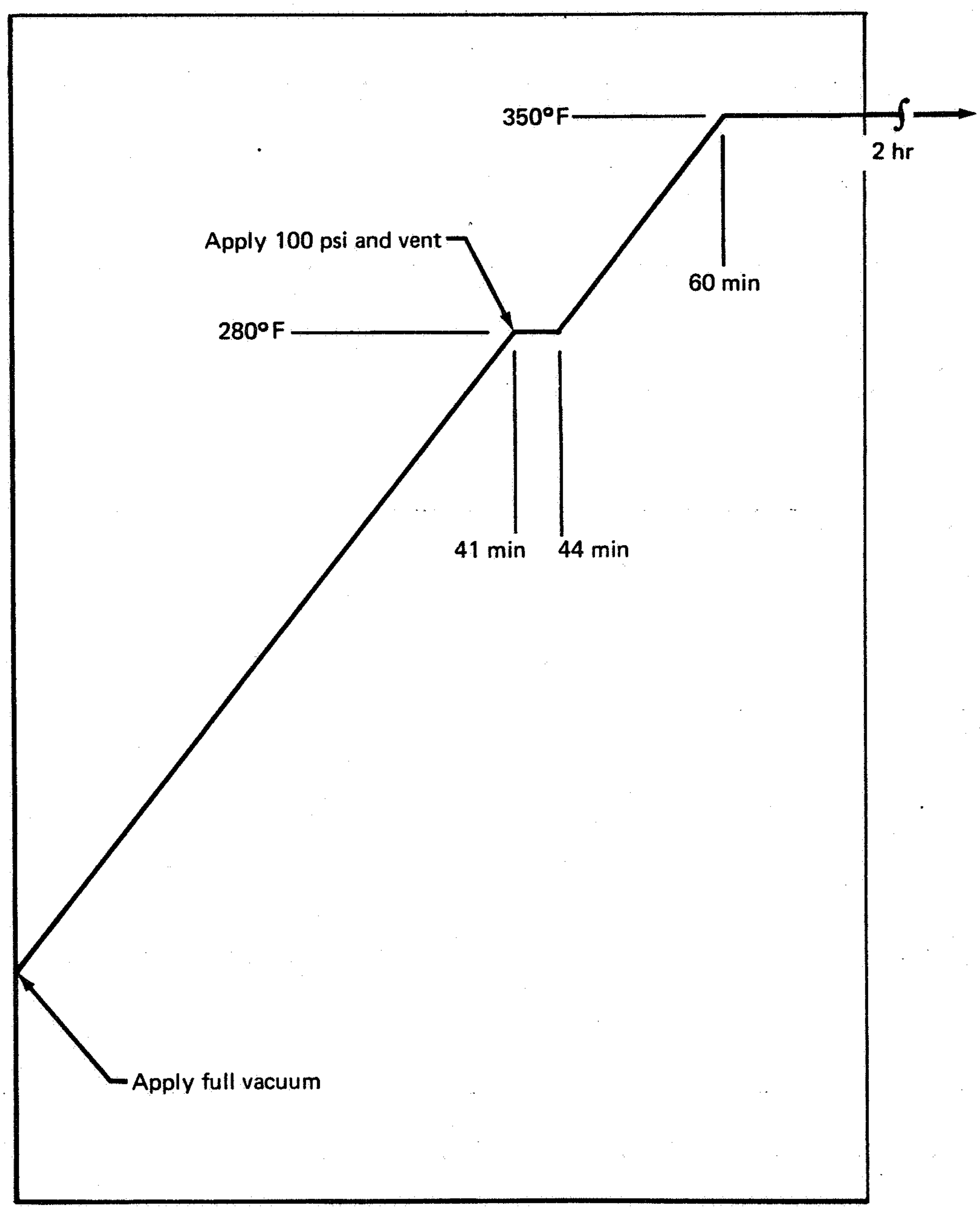


FIGURE 9.—CURE CYCLE—HERCULES

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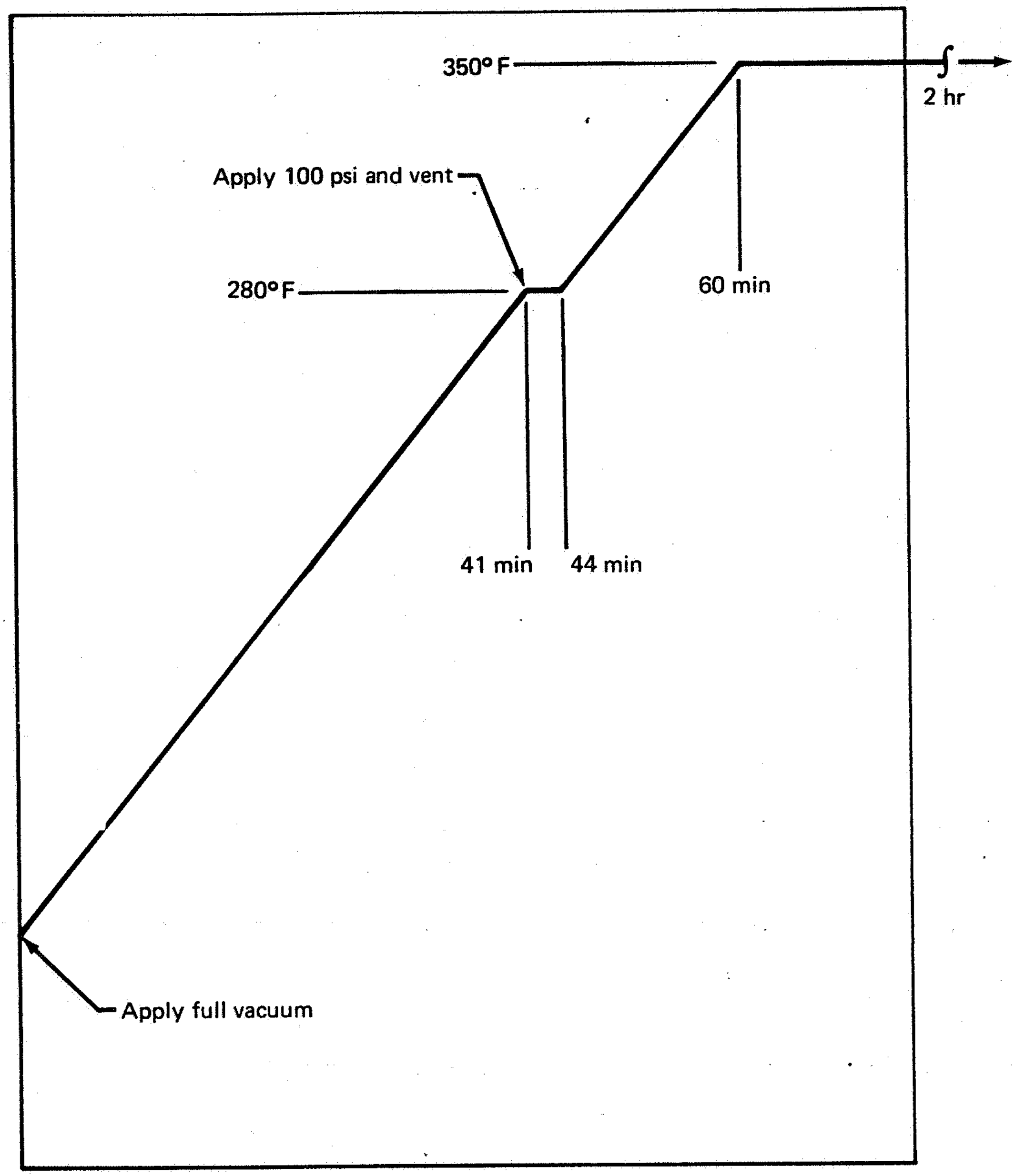


FIGURE 10.—CURE CYCLE—FOTHERGIL AND HARVEY

A = 0.500 in. for 0° tension
B = 1.000 in. for 90° and crossplied tension

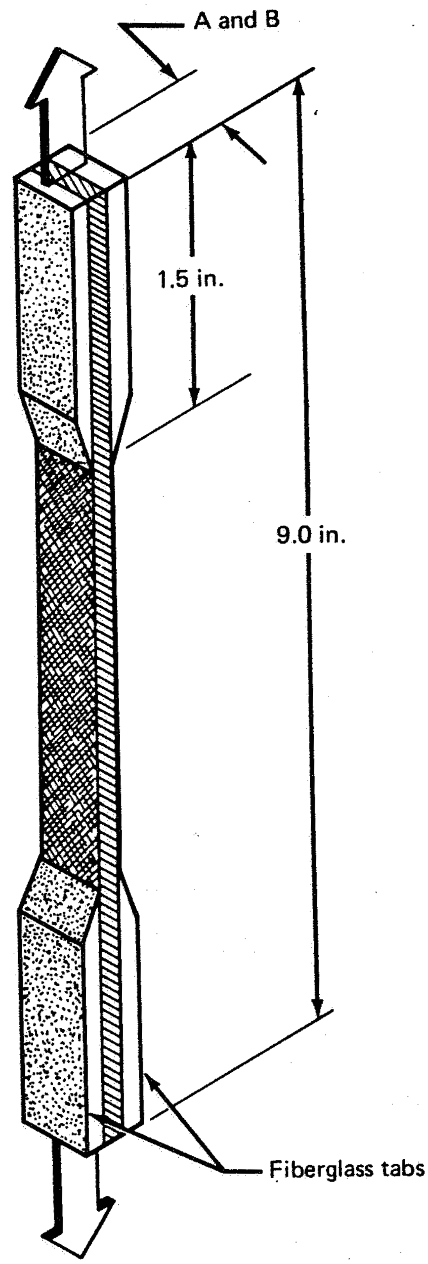


FIGURE 11.—TENSILE TEST SPECIMEN

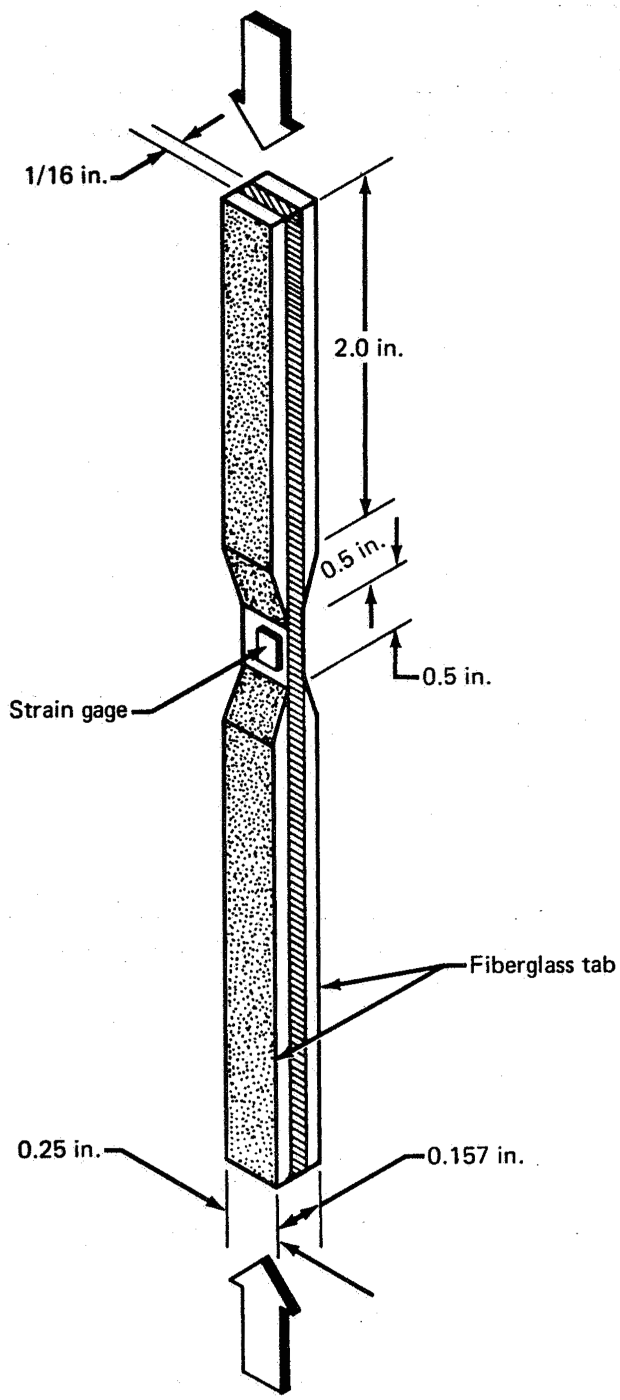


FIGURE 12.—COMPRESSION TEST SPECIMEN

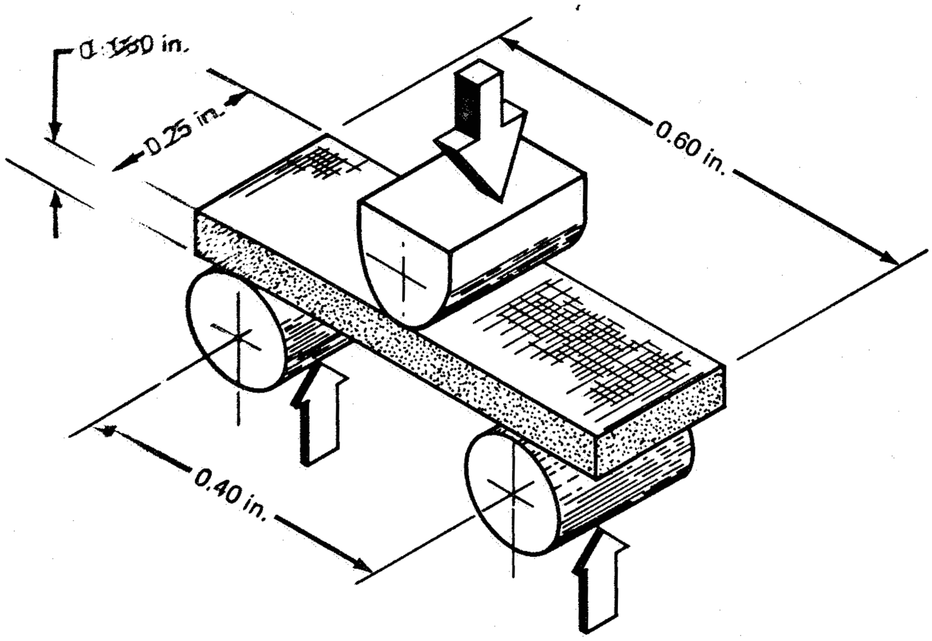


FIGURE 13.—SHORT BEAM SHEAR TEST SPECIMEN

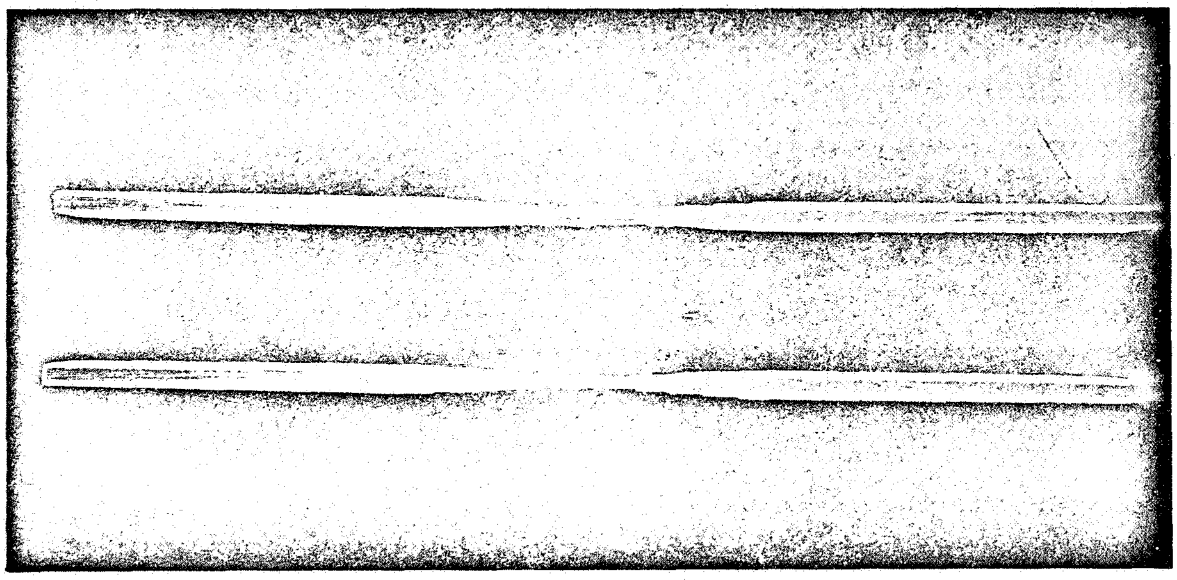


FIGURE 14.—TESTED AND UNTESTED COMPRESSION SPECIMENS—NO STRAIN GAGES, EDGE VIEW

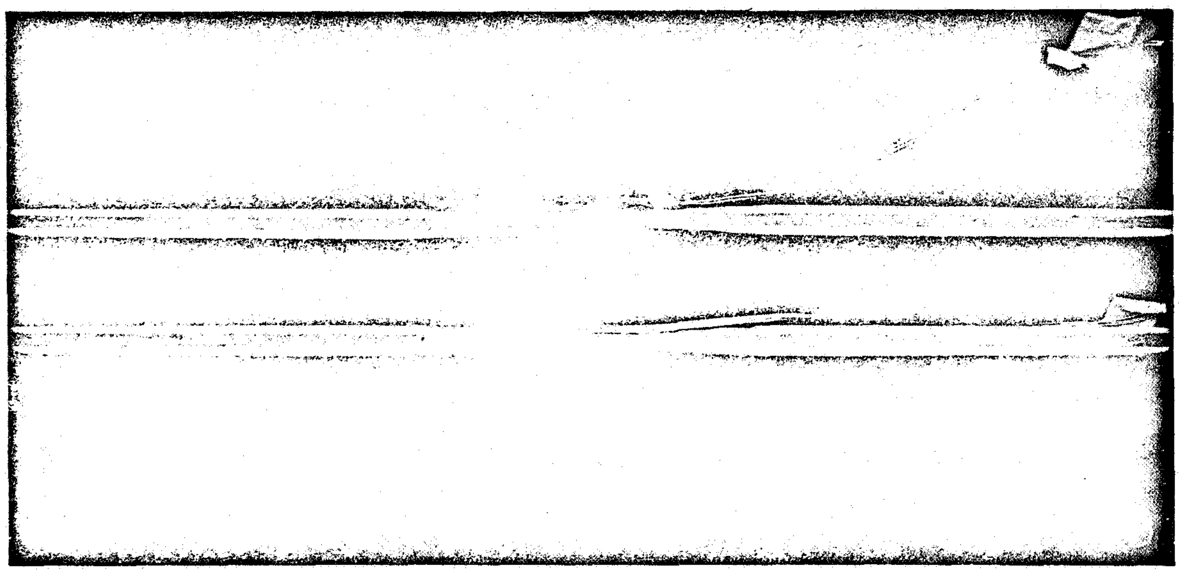


FIGURE 15.—TESTED AND UNTESTED COMPRESSION SPECIMENS—WITH STRAIN GAGES, EDGE VIEW

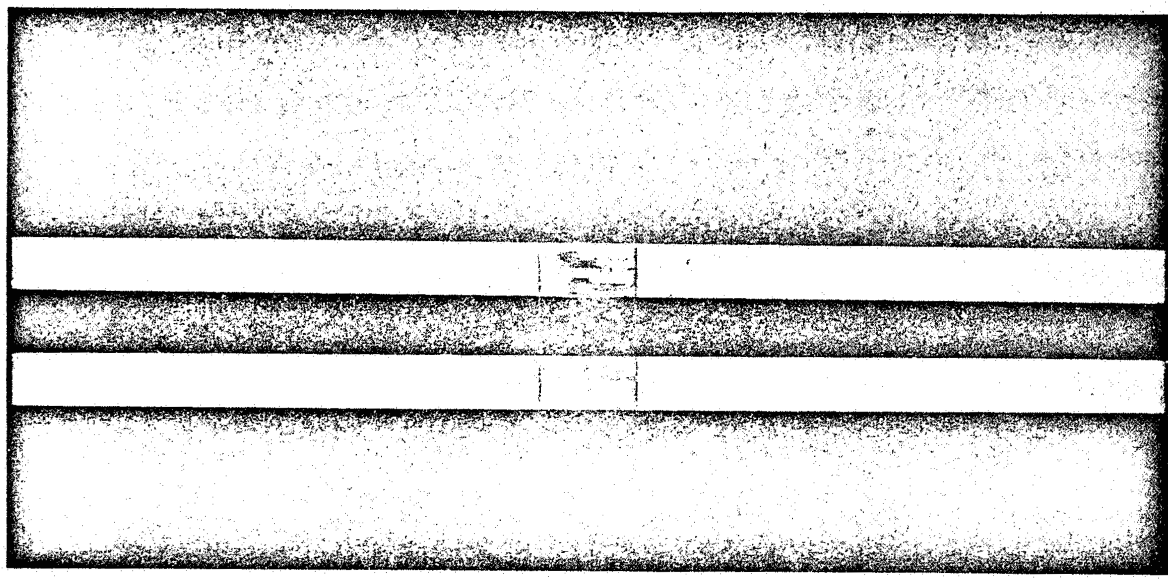


FIGURE 16.—TESTED AND UNTESTED COMPRESSION SPECIMENS—NO STRAIN GAGES, FRONT VIEW

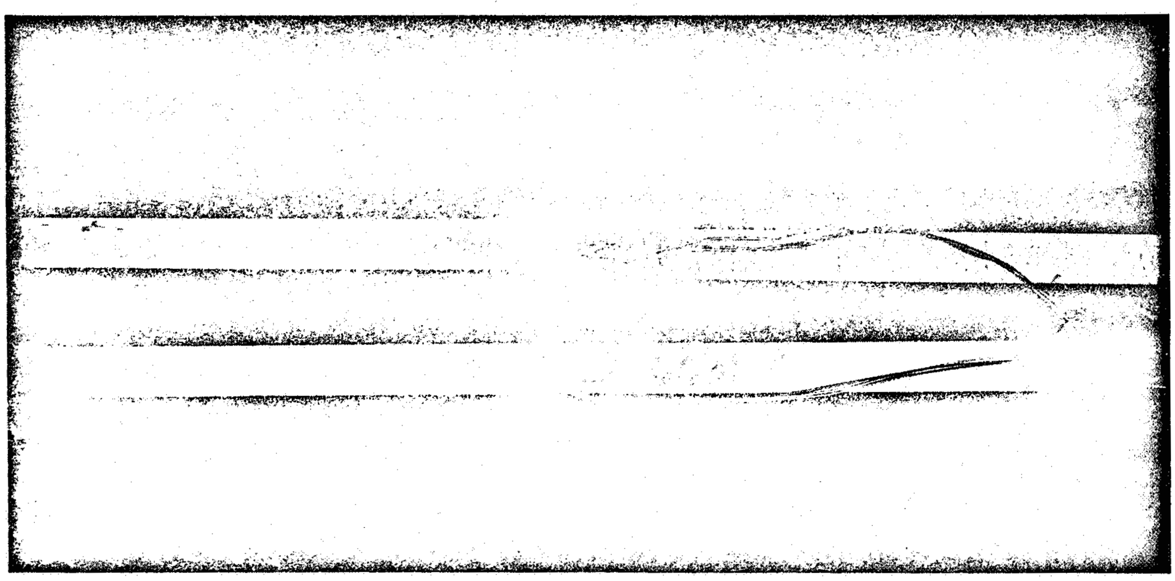


FIGURE 17.—TESTED AND UNTESTED COMPRESSION SPECIMENS—WITH STRAIN GAGES, FRONT VIEW

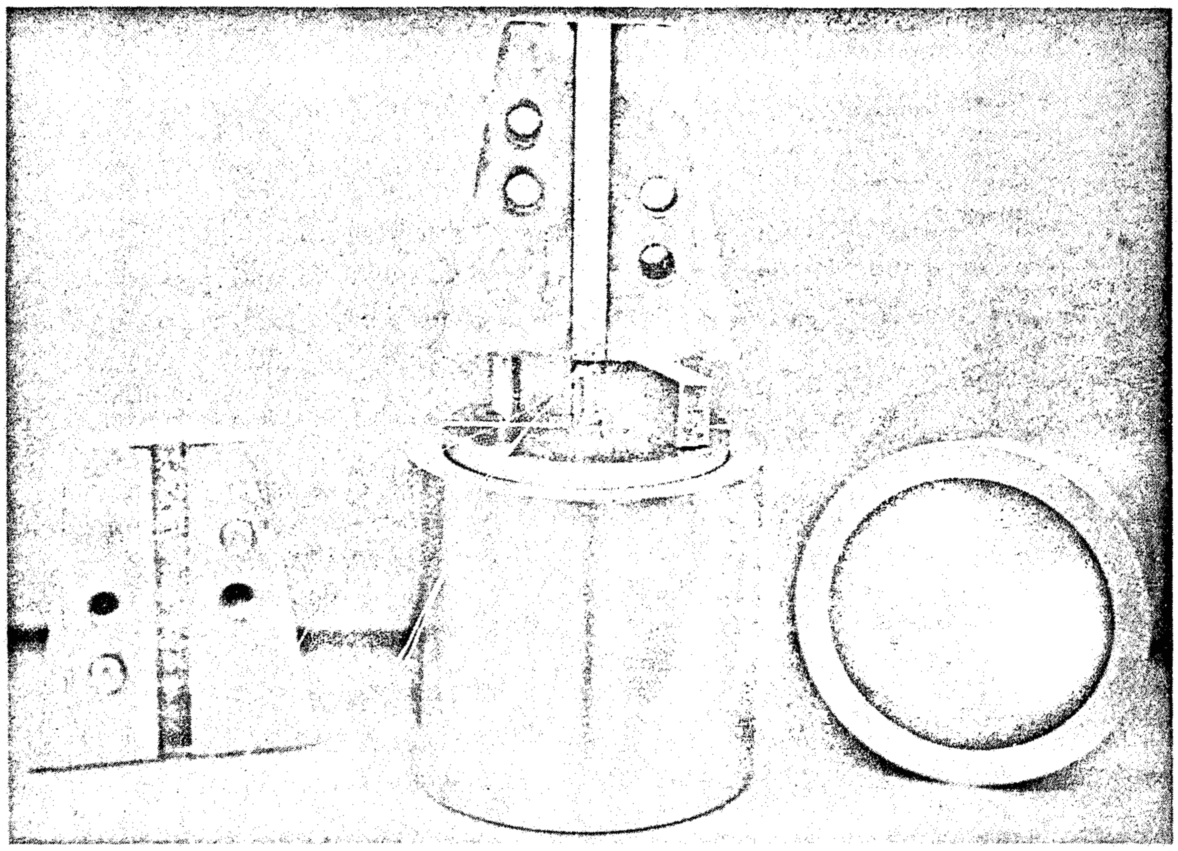


FIGURE 18.—CELANESE COMPRESSION TEST FIXTURE

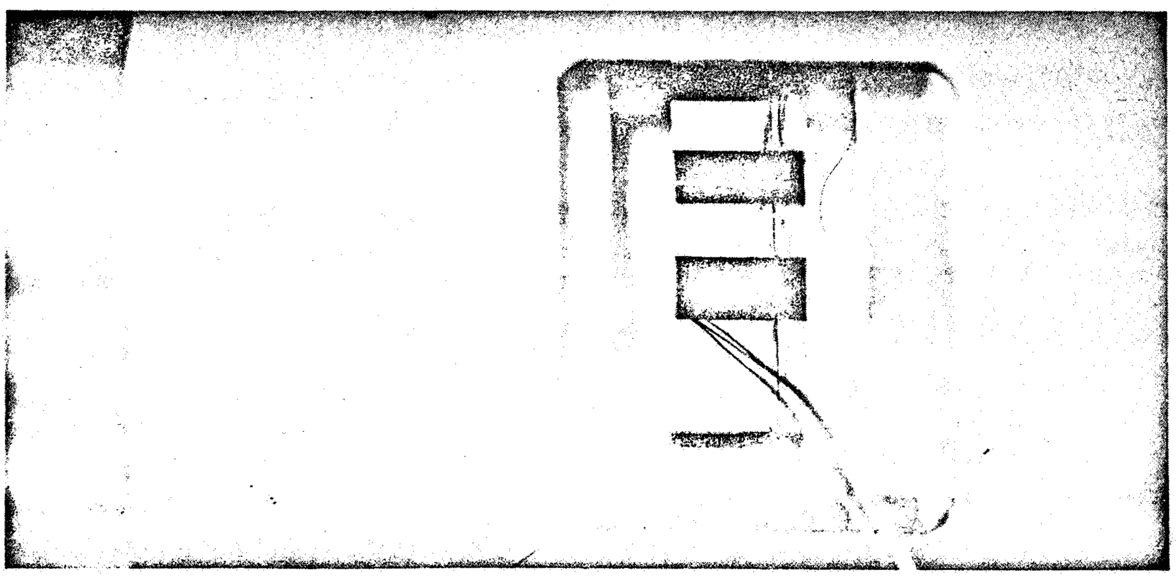


FIGURE 19.—COMPRESSION SPECIMEN MOUNTED IN CELANESE TEST FIXTURE

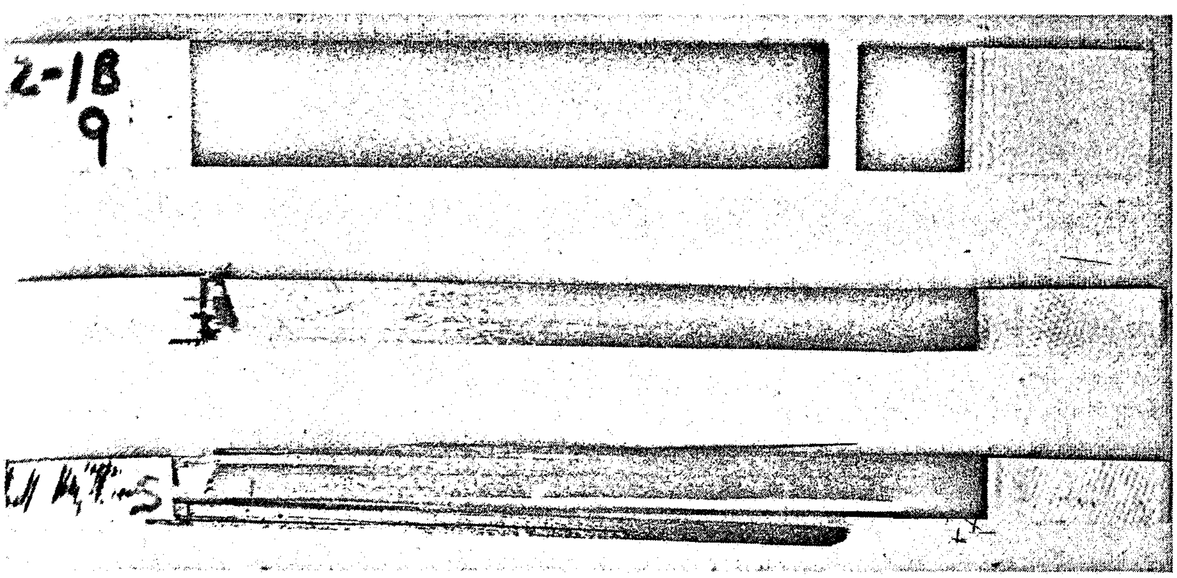
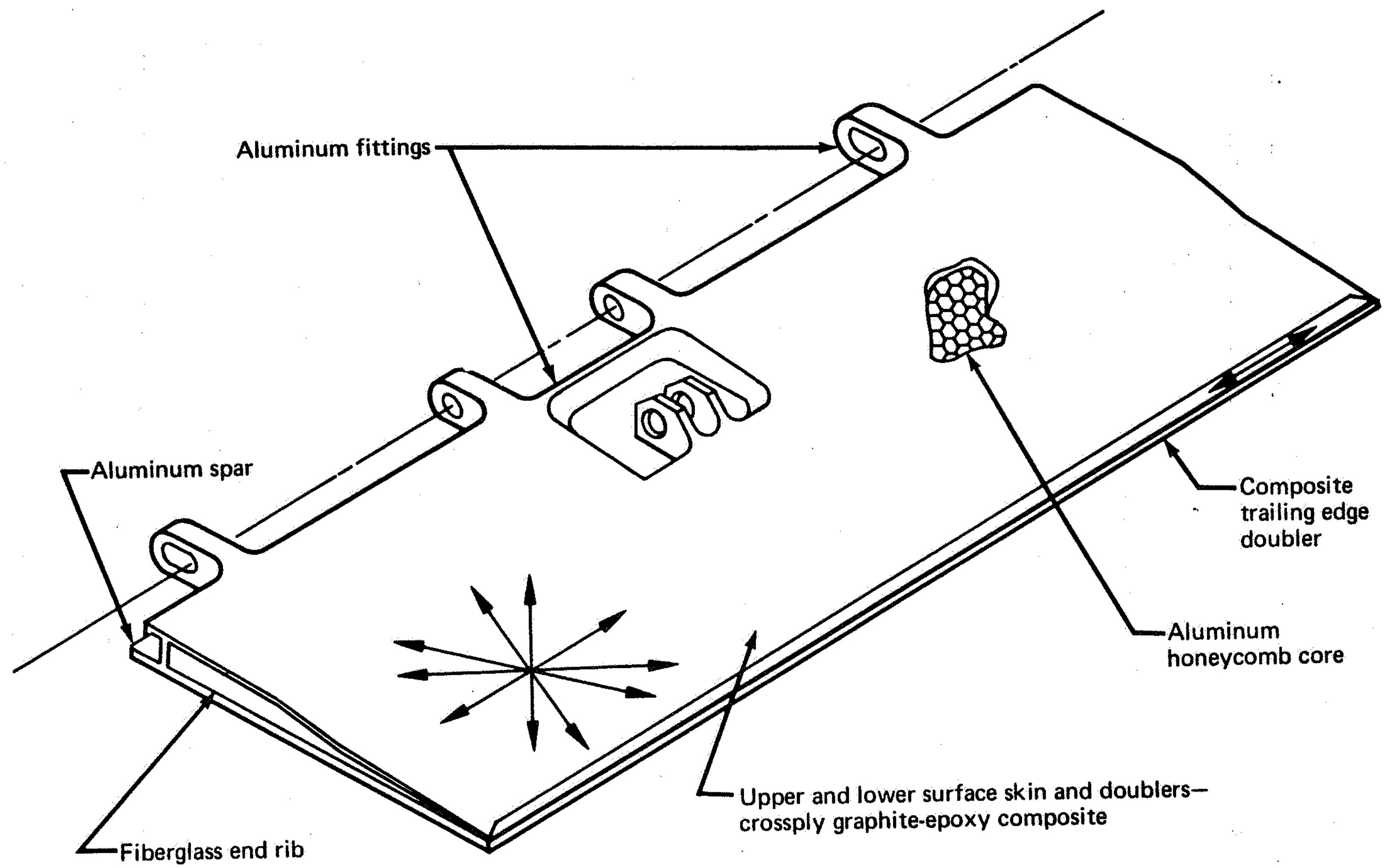


FIGURE 20.—FAILED TENSILE SPECIMENS—UNIDIRECTIONAL, 90° LOADING; CROSSPLIED, 0° LOADING; UNIDIRECTIONAL, 0° LOADING

30



Note: All structure is adhesively bonded

FIGURE 21.—737 GRAPHITE-EPOXY FLIGHT SPOILER

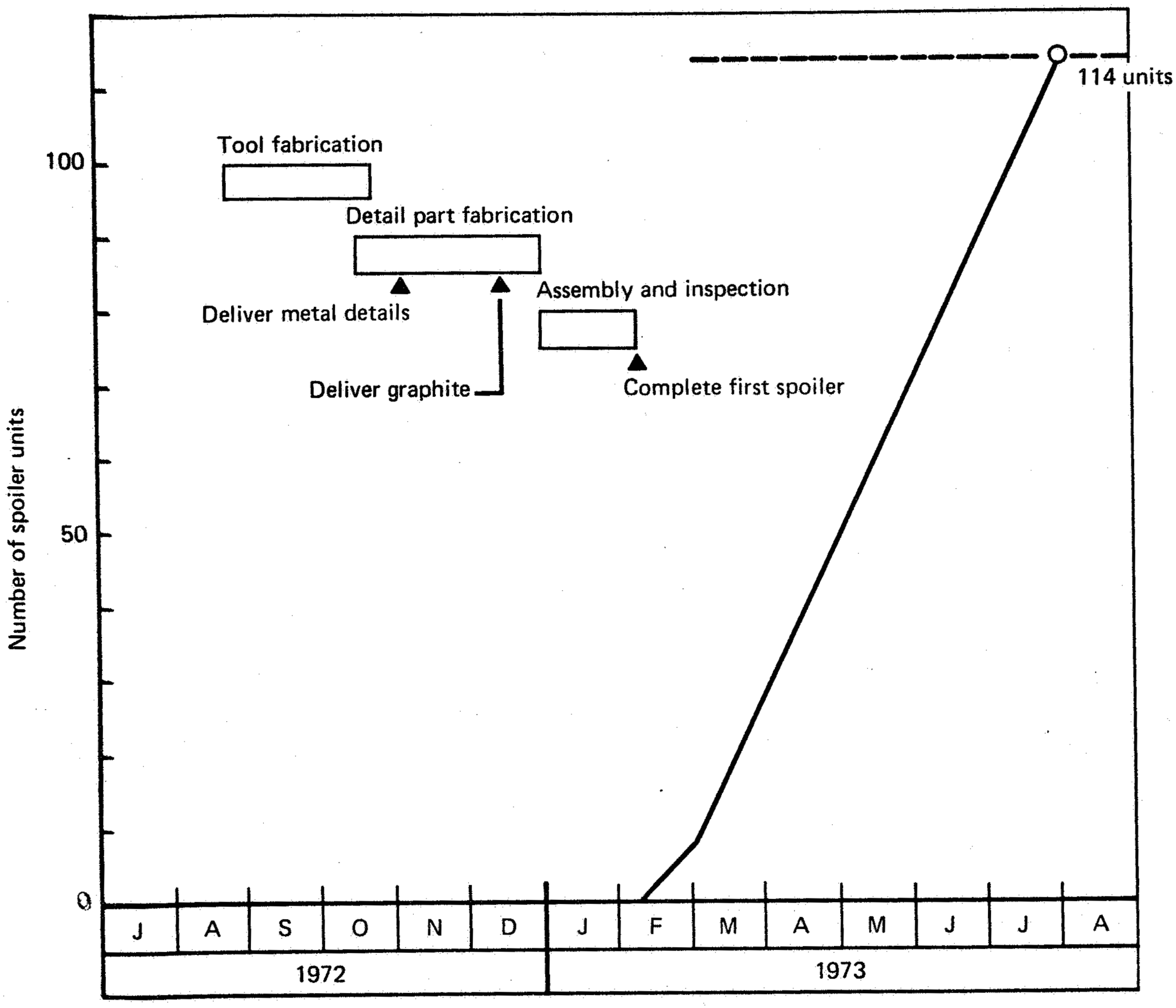


FIGURE 22.–SPOILER PRODUCTION SCHEDULE

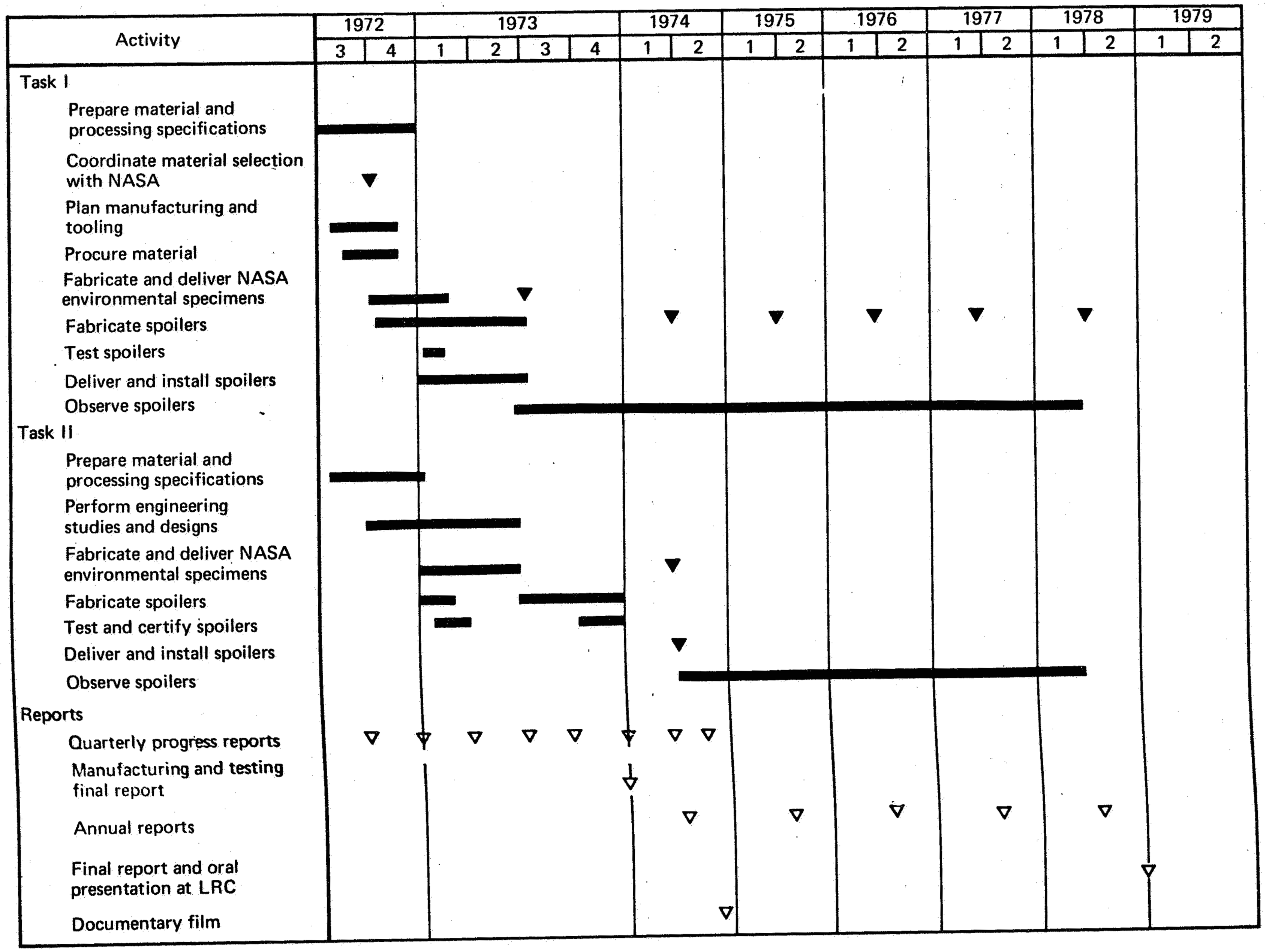


FIGURE 23.—PROGRAM SCHEDULE

APPENDIX

MECHANICAL PROPERTY DATA

Laboratory data compiled to screen the several graphite suppliers have been assembled in this appendix. All testing was in Boeing Structures Technology laboratories located in Renton, Washington.

Test specimens are individually identified according to the following code:

1-2AC-3

Specimen number:

- 1-6 = room temperature test
- 7-9 = 160° F test
- 10-15 = 30 days at 140° F and 100% relative humidity
- 16-21 = 42 days at 140° F and 100% relative humidity

Test type:

- C = compression
- S = short-beam shear
- T = tensile

Load direction:

- A = 0°
- B = 90°

Layup type

- 1 = unidirectional
- 2 = crossplied $[0°, -45°, +45°, 90°, 90°, +45°, -45°, 0°]_2$

Vendor number (1 through 6)

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DATA SHEET

MECHANICAL PROPERTIES

NML ______________________ TEST Compression

TITLE ______________________ DATE 9-20-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs	y in/in	REMARKS
1-1AC-1	R.T.	.0798	.2504	.019982	2675	133,870	—			broken strain guage
-2		.0806	.2525	.020352	2670	131,191	20.082		408,719	
-3		.0889	.2515	.02233	3275	146,644	18.251		407,609	
-4		.0782	.2515	.019667	2,250	114,405	—			
-5		.0863	.2517	.021722	2,630	121,075	—			
-6	↓	.0876	.2525	.022119	2,900	126,590	—			ave 128,963; ave 19.167
1-2B-1	R.T.	.0803	.2525	.020276	1820	89,761	7.029		142,518	
-2		.0781	.2530	.019759	1535	77,686	7.196		142,180	
-3		.0805	.2539	.020439	1700	83,174	7.230		147,783	
-4		.0789	.2536	.020009	1350	67,470	—			
-5		.0776	.2533	.019656	1300	66,140	—			
-6	↓	.0798	.2538	.020253	1450	71,595	—			ave 75,971; ave 7.152
2-1A-1	R.T.	.0627	.2524	.015825	1960	123,855	22.250		352,113	
-2		.0685	.2523	.017283	2,250	130,186	21.117		364,964	
-3		.0644	.2523	.016248	1,900	116,937	21.223		344,828	
-4		.0595	.2513	.014946	1875	125,450	—			
-5		.0616	.2524	.015548	1990	127,990	—			
-6	↓	.0624	.2525	.015756	1940	123,130	—			ave 124,591; ave 21.530

DATA SHEET
MECHANICAL PROPERTIES

NML ________ TEST *Compression*

TITLE ________ DATE *9-20-72*

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs.	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
2-28-1	R.T.	.0637	.2517	.016033	950	59253	7.591		121,508	
-2		.0632	.2500	.015800	775	4905[illegible]	7.206		113,854	
-3		.0626	.2507	.015694	965	[illegible]1488	6.351		99,668	
-4		.0618	[illegible]	.015617	820	52,505	—			
-5		.0627	.2520	.015800	780	49,365	—			
-6	↓	[illegible]	.2528	.016553	820	49,525	—			ave 53,531; ave 7.049
3-120-1	R.T.	.0961	.2522	.024236	3620	149,365	15.022		344,078	
-2		.0851	.2522	.021462	2525	117,650	14.714		315,789	
-3		[illegible]	.2521	.021076	2740	130,006	13.660		289,908	
-4		.0788	.2515	.019818	2,225	112,270	—			
-5		.0809	.2522	.020403	2,400	117,630	—			
-6	↓	.0825	.2523	.020815	2,630	126,350	—			ave 125,545; ave 14.465
3-28-1	R.T.	.0860	.2509	.021577	1335	61,871	4.697		101,357	
-2		.0816	.2515	.020522	1400	68,219	5.475		112,360	
-3		.0805	.2513	.020230	1370	67,721	7.585		153,453	
-4		.0825	.2513	.020732	1320	63,670	—			
-5		.0864	.2505	.021643	1260	58,217	—			
-6	↓	.0838	.2527	.021176	1550	73,196	—			ave 65,482; ave 5.919

DATA SHEET
MECHANICAL PROPERTIES

NML ____________ TEST Compression

TITLE ____________ DATE 10-4-72

SPECI-MEN NO	TEST TEMP °F	DIMENSIONS THKNS in	WIDTH in	AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi x 10⁶	P_y lbs.	y in/in	REMARKS
3-1AC-10	R.T.	.0813	.2537	.020621	2320	112,479				
-11		.0885	.2534	.022426	2810	125,301				
-12		.0938	.2533	.023760	3375	142,045				
-13		.0806	.2527	.020368	2150	105,558				
-14		.0835	.2541	.021217	2720	128,199				
-15		.0832	.2529	.021041	2590	123,093				ave 122,779
5-1AC-10	R.T.	.0576	.2529	.014567	1365	93,705				
-11		.0562	.2518	.014151	1310	92,573				
-12		.0595	.2524	.015018	1495	99,547				
-13		.0642	.2516	.016153	1755	108,649				
-14		.0655	.2535	.016607	1770	106,601				
-15		.0634	.2529	[illegible]	1780	111,014				ave 102,015

All specimens — 30 days exposure to 140°F, 100% R.H.

DATA SHEET

MECHANICAL PROPERTIES

NML ______________ TEST *Compression*

TITLE ______________ DATE ______________

SPECI-MEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in^2	ULT LOAD lbs.	ULT. STRESS psi	MODULUS psi $\times 10^6$	P_y lbs.	y in/in	REMARKS
1-1AC-7	160°F	.0842	.2506							
-8	↓	.0789	.2517							
-9	↓	.0860	.2519							
2-1AC-7	160°F	.0638	.2529							
-8	↓	.0670	.2511							
-9	↓	.0642	.2522							
3-1AC-7	160°F	.0854	.2521							
-8	↓	.0854	.2521							
-9	↓	.0826	.2532							
5-1AC-7	160°F	.0590	.2523							
-8	↓	.0567	.2527							
-9	↓	.0539	.2512							
6-1AC-7	160°F	.0	.2							
-8	↓	.0	.2							
-9	↓	.0	.2							

DATA SHEET
MECHANICAL PROPERTIES

NML ______ TEST Compression

TITLE ______ DATE 9-20-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
5-1R-1	R.T.	.0606	.2506	.015186	1500	98,775	16.856		255,973	
-2		.0619	.2528	.015648	1630	104,167	20.615		322,581	
-3		.0626	.2521	.015791	1690	107,010	—			strain gauge did not work
-4		.0616	.2532	.015597	1700	108,995	—			
-5		.0569	.2527	.014379	1420	98,755	—			
-6	↓	[illegible]	.2514	.014757	1540	104,355	—			ave 103,690 ; ave 18.736
5-2R-1	R.T.	.0568	.2540	.014427	900	62,383	5.339		77,022	
-2		.0584	.2535	.014804	980	66,198	6.840		101,266	
-3		.0591	.2515	.014864	748	50,323	5.689		84,567	
-4		.0627	.2530	.015863	990	62,410	—			
-5		.0607	.2533	.015375	905	58,860	—			
-6	↓	.0612	.2535	.015514	900	58,010	—			ave 59,697; ave 5.956

DATA SHEET
MECHANICAL PROPERTIES

NML ______________ TEST *Compression*

TITLE ______________ DATE *10-2-72*

SPECIMEN NO.	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
1-1K-10	R.T.	.0836	.2524	.021101	2350	111,369				
-11	↓	.0810	.2520	.020412	2200	107,780				
-12		.0804	.2528	.020325	2120	104,305				
-13		.0871	.2524	.021984	2500	113,719				
-14		.0855	.2529	.021623	2630	121,630				
-15		.0865	.2525	.021841	2500	114,464				ave 112,211
2-1K-10	R.T.	.0652	.2555	.016659	1980	118,855				
-11	↓	.0645	.2537	.016364	2010	122,831				
-12		.0667	.2557	.017055	2000	117,268				
-13		.0641	.2558	.016397	1720	104,897				
-14		.0608	.2554	.015528	1430	92,092				dip along center of specimen
-15		.0629	.2546	.016014	1520	94,917				ave 108,477

All specimens – 30 days exposure to 140°F, 100% R.H.

DATA SHEET
MECHANICAL PROPERTIES

NML 725331 TEST short beam shear

TITLE DATE 9-5-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	WIDTH in	AREA in^2	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi $\times 10^6$	P_y lbs	y in/in	REMARKS
1-1AS-1	R.T.	.0881	.2516	.022166	316	10,692				use .43 span
-2		.0975	.2522	[illegible]	350	11,896				
-3		.0966	.2523	.021373	356.5	12,213				
-4		.0877	.2523	.022129	326	11,050				
-5		.0877	.2520	.022100	388	13,167				
-6		.0923	.2526	.020989	357	12,959				11983 ave
1-1AS-7	160°F	.0861	.2521	[illegible]	[illegible]	9,689				use .43 span
-8		.0966	.2524	.021858	287	9,848				
-9		.0809	.2523	.020411	[illegible]	9,774				9,770 ave
2-1AS-1	R.T.	.0647	.2528	.016356	200	9,171				use .32 span
-2		.0616	.2528	.015597	156	7,513				
-3		.0636	.2535	.016123	175.5	8,164				
-4		.0640	.2533	.016211	159	7,356				
-5		.0623	.2533	.015781	157.5	7,580				
-6		.0633	.2523	.015971	162	7,608				7,9[illegible] ave
2-1AS-7	160°F	.0663	.2504	.016602	153	6,912				use .32 span
-8		.0658	.2517	.016562	129	5,842				
-9		.0654	.2528	.016533	177.5	8,052				6,93[illegible] ave

DATA SHEET

MECHANICAL PROPERTIES

NML 725001

TITLE

TEST short beam shear

DATE 9-6-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs	y in/in	REMARKS
3-1AS-1	R.T.	.0976	.2515	.024546	526	16,072				use .43 span
-2		.0778	.2501	.019458	296	11,409				
-3		.0894	.2467	.022055	346.5	11,783				
-4		.0835	.2460	.020541	361.5	13,199				
-5		.0818	.2514	.020565	350	12,764				
-6		.0949	.2516	.023877	507	15,988				13,536 ave
3-1AS-7	160°F	.0787	.2493	[illegible]	[illegible] 89	[illegible]				use .43 span
-8		[illegible]	.2502	[illegible]	[illegible]	12,694				
-9		.0799	.2497	.019951	245	9,210				10,480 ave
5-1AS-1	RT	.0629	.2524	.015876	224	10,592				use .32 span
-2		.0625	.2522	[illegible]	218	10,392				
-3		.0558	.2507	[illegible]	19[illegible]	10,29[illegible]				
-4		.0567	.2522	[illegible]	193	10,122				
-5		.0535	.2513	.013445	166.5	9,288				
-6		.0604	.2504	.015124	201.5	9,992				10,108 ave
5-1AS-7	160°F	.0636	.2532	.016104	160	7,452				use .32 span
-8		.0628	.2529	.015882	154	7,272				
-9		.0612	.2573	.015380	165	8,046				7,590 ave

DATA SHEET
MECHANICAL PROPERTIES

NML 725001

TITLE

TEST Short Beam Shear

DATE 9-22-72

SPECIMEN NO.	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT LOAD lbs.	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
4-1AS-1	RT	.1033	.2526	.026094	367	10,548				
-2		.1036	.2507	.025973	350	10,107				
-3		.1021	.2501	.025535	326.5	9,590				
-4		.1034	.2521	.026069	330	9,495				
-5		.1015	.2495	.025374	355	10,514				
-6		.1030	.2503	.025[illegible]81	375	10,909				ave 10,194
4-1AS-7	160°F	.1024	.2545	.026061	[illegible]	7,540				
-8		.1048	.2529	.026504	330	9,338				
-9		.1062	2484	.026380	[illegible]	8,330				ave 8,403

DATA SHEET

MECHANICAL PROPERTIES

NML 331 62 6

TITLE

TEST Short beam Shear

DATE 9-20-72

SPECI-MEN NO.	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi x 10⁶	P_y lbs.	y in/in	REMARKS
6-4AS -1	R.T.	.0812	.2524	.020495	175	6,404				
-2		.0774	.2524	.019536	188.5	7,237				
-3		.0944	.2533	.023912	316.5	9,927				
-4		.0990	.2533	.025077	322.5	9,645				
-5		.0995	.2523	.025104	228.5	6,827				
-6		.0769	.2505	.019263	173	6,736				ave 7,796
-7	160°F	.0957	.2517	.024088	238.5	7,426				
-8		.0991	.2531	.025082	254	7,595				
-9		.0953	.2520	.024016	246	7,682				ave 7568

DATA SHEET
MECHANICAL PROPERTIES

NML ______________

TITLE ______________

TEST Short beam shear

DATE 10-2-72

SPECI-MEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi x 10⁶	P_y lbs.	y in/in	REMARKS
1-1AS-10	R.T.	.0883	.2525	.022296	290	9,755				use .43 span
-11	↓	.0851	.2534	.021564	306.5	10,660				
-12		.0804	.2519	.020253	286.5	10,610				
-13		.0885	.2536	.022444	283	9,457				
-14		.0820	.2537	.020803	258	9,302				
-15		.0857	.2535	.021573	[illegible]	10,238				ave 10,004
2-1AS-10	R.T.	.0648	.2557	.016569	[illegible]	6,745				use .36 span.
-11	↓	.0655	.2553	.016722	[illegible]	9,602				
-12		.0648	.2551	.016530	134	6,080				
-13		.0636	.2557	.016263	110.5	5,096				
-14		.0646	.2562	.016551	143	6,480				
-15		.0652	.2565	.016826	145	6,463				ave 6,411

All specimens - 30 days exposure to 140°F, 100% R.H.

DATA SHEET
MECHANICAL PROPERTIES

NML ______________________ TEST Short beam shear

TITLE ______________________ DATE 10-4-72

SPECIMEN NO.	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs.	ULT. STRESS psi	MODULUS psi x 10⁶	P_y lbs.	y in/in	REMARKS
3-1A-10	R.T.	.0905	.2514	.022752	340	11,208				use .43 span
-11		.0894	.2485	.022216	305	10,297				
-12		.0820	.2490	.020418	303	11,130				
-13		.0819	.2511	.020565	320	11,676				
-14		.0845	.2539	.021455	352.5	11,623				
-15		.0831	.2513	.020883	325	11,672				ave 11,267
5-1A-10	R.T.	.0548	.2505	.013727	158	8,633				use .36 span
-11		.0597	.2495	.014895	137.5	9,240				
-12		.0596	.2524	.015043	[illegible]	9,373				
-13		.0598	.2511	.015016	172	9,591				
-14		.0602	.2531	.015237	187	9,205				
-15		.0565	.2510	.014182	174.5	9,228				ave 9,045
All specimens – 30 days exposure to 140°F, 100% R.H.										

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DATA SHEET
MECHANICAL PROPERTIES

NML ______ TITLE ______

TEST *short beam shear* (R[illegible])

DATE ______

SPECIMEN NO.	TEST TEMP °F	DIMENSIONS THKNS in	WIDTH in	AREA in²	ULT LOAD lbs.	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
						x̄	x̄			
1-1A5-[illegible]	R.T.	.0823	.2508	.020641	364.5	13,244	[illegible]			use .43 span
-23	↓	.0829	.2517	.020866	361.5	12,936	[illegible]			[illegible] 6203 [illegible]
-24		.0832	.2521	.020975	372.5	13,319	171.8			[illegible]
-25		.0839	.2510	.021059	369.5	13,159	[illegible]			S : 34[illegible]
-26		.0831	.2502	.020792	363.5	13,112	171.92			
-2[illegible]	↓	.0873	.2496	.021790	377.5	12,993	[illegible]			13,127 ave
						[illegible]	[illegible]			
2-1A5-2[illegible]	R.T.	.0641	.2514	.016115	146.5	9,145	[illegible]			use .36 span
-23	↓	.0636	.2514	.015989	155.5	8,701	75.71			[illegible]
-24		.0637	.2508	.015976	158.5	9,441	55.39			Σx_i^2 : 45.39
-25		.0671	.2497	.016755	[illegible]	9,176	[illegible]			S = 756 psi
-26		.0635	.2518	.015989	[illegible]	8,514	[illegible]			
-27		.0637	.2508	.015976	168.5	9,910	62.5[illegible]			
-28	↓	.0631	.2511	.015844	146.0	9,379	50.42			8,323 ave
						[illegible]	488.39			

DATA SHEET
MECHANICAL PROPERTIES

NML 37/1626

TITLE

J. SMITH

TEST Tensile

DATE 9-5-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	WIDTH in	AREA in²	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
1-1AT-1	R.T.	.0912	.4988	.045[illegible]	7250	159,372	18.708		[illegible]	
-2		.0967	.5012	[illegible]466	8[illegible]	169,191	17.036		82,[illegible]	
-3		.0958	.5009	.047[illegible]	7990	166,507	16.294		[illegible]	
-4		.0957	.5015	.047994	6750	140,643	16.818		[illegible]	
-5		.0888	.5005	.044444	6180	[illegible],051	16.565		[illegible]	
-6		.0965	.5028	.048[illegible]	92[illegible]	191,055	16.236		[illegible]	160,990 ave / 16.940 ave
1-1AT-7	160°F	.0946	.5005	.047347	925[illegible]	195,366	19.347		916,031	[illegible]
-8		.0966	.5013	.048426	88[illegible]	182,549	19.964		118,3[illegible]	
-9		.0919	.5027	.0[illegible]	70[illegible]	153,470	19.868		37[illegible],6[illegible]1	177,128 ave / 19.060 ave
1-2AT-1	R.T.	.0811	.5015	.040672	2720	66,876	5.545		21,[illegible]	
-2		.0805	.5018	.040395	3190	78,970	5.447		[illegible]	
-3		.0809	.5018	.040596	3780	93,406	5.434		[illegible],588	
-4		.0805	.5014	.040[illegible]	3010	74,573	5.412		218,447	
-5		.0793	.5010	.039729	2660	66,954	5.355		217,766	
-6		.0795	.5013	.039853	28[illegible]	71,262	5.289		210,773	72,007 ave / 5.380 ave

DATA SHEET

MECHANICAL PROPERTIES

NML 33/6.56

TITLE

J. SMITH

TEST Tensile

DATE

SPECIMEN NO.	TEST TEMP. °F	DIMENSIONS THKNS in	WIDTH in	AREA in²	ULT LOAD lbs.	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS	
2-1AT-1	R.T.	.0636	.4963	.031565	5920	187,550	23.467		790,041		
-2	↓	.0639	.4986	.031861	5810	182535	23.589		751,566		
-3		.0621	.4997	.031031	6270	202,056	22.973		712,871		
-4		.0633	.4931	.031213	5707	182,616	23.732		740,741		
-5		.0646	.4952	.031995	6350	198,500	24.571		786,076		
-6		.0643	.5008	.032201	6810	212,416	24.146		777,539	194,279 ave	23.746 ave
2-1AT-7	160°F	.0640	.4997	.031981	6950	217,317	25.525		816,321	[illegible]	
-8	↓	.0610	.5104	.031134	6050	194,321	24.089		750,000		
-9		.0634	.4998	.031687	6560	207,025	28.122		991,037	206,221 ave	25.912 ave
2-2iF1	RT	.0599	.5019	.030064	2000	66,525	9.831		[illegible]		
-2	↓	.0616	.5023	.030942	1[illegible]	63,991	8.788		291,0[illegible]		
-3		.0624	.5019	.031319	2160	68,968	9.300		291,262		
-4		.0619	.4987	.030876	1870	61,224	8.862		293,5[illegible]6		
-5		.0619	.5018	.031061	1820	58,594	9.027		[illegible]		
-6		.0619	.5017	.031055	2030	65,368	9.057		291,[illegible]	64,112 ave	9.144 ave

DATA SHEET

MECHANICAL PROPERTIES

NML 725 001

TITLE

TEST Tensile

DATE 4-7-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS	
3-1AT-1	R.T.	.0949	.4999	.047[illegible]	9380	197,920	17.584		833,333		
-2		.0815	.5019	.040905	8080	197,531	18.567		759,4[illegible]		
-3		.0804	.5013	.040345	8370	207,46[illegible]	17,260		[illegible]		
-4		.0841	.5024	.0422[illegible]	7450	176,323	18.245		990,[illegible]		
-5		.0855	.5025	.042964	7480	174,097	19.727		204,571		
-6		.0811	.5019	[illegible]	7610	186960	18.124		937,705	190,217 ave	18.085 ave
3-1AT-7	160°F	.0854	.5027	.042931	76[illegible]	177960	20.382		895,91[illegible]		
-8		.0843	.5017	[illegible]293	722[illegible]	170,714	19.613		824,497		
-9		.0806	.5019	.040453	7740	191,233	19,180		775,862	180,002 ave	19.725 ave
3-2AT-1	R.T.	.0758	.5015	.038014	1960	51,560	9.492		28[illegible]		
-2		.0804	.5012	.040296	2250	55,859	6.588		265,495		
-3		.0815	.5014	.040864	2410	58,976	7.341		[illegible]		
-4		.0795	.5015	.0398[illegible]	[illegible]	55,933	7.500		[illegible]		
-5		.0802	.5003	[illegible]	2410	60,004	7.918		[illegible]		
-6		.0801	.5004	.040082	2230	55,086	7.386		[illegible]	56,238 ave	7.371 ave

DATA SHEET

MECHANICAL PROPERTIES

NML 725001

TITLE

TEST Tensile

DATE 9-22-72

SPECI-MEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs	y in/in	REMARKS
4-1AT-1	R.T.	.1041	.5017	.052227	7650	146,477	23.453		1,22490	
-2		.1122	.5013	.056246	9130	162,323	24.244		1,363,600	
-3		.1087	.5020	.054567	9110	166,951	21.112		1,157,0[illegible]	
-4		.1072	.5025	.053[illegible]	[illegible]	175,05[illegible]	22.965		1,239,[illegible]	
-5		.1098	.5006	[illegible]	10,020	182,295	21.979		1,208,100	
-6		.1047	.5005	.052492	8760	167,169	23.249		1,218,200	avc 166,712 ; avc 22,834
4-1AT-7	1500°F	.1040	.5002	.052021	8960	172,233	23.931		1,2247[illegible]	
-8		.1058	.5014	.053048	[illegible]	170,412	23.047		1,222390	
-9		.1077	.5019	.054055	[illegible]	174,822	21.553		1,165,050	avc 172,491 ; avc 22.842
4-JAF1	R.T.	.1259	.5014	.063126	3280	51,960	8.325		525,550	
-2		.1277	.5024	.064156	[illegible]	61,850	7.926		505,[illegible]	
-3		.1301	.5005	[illegible]115	[illegible]	63,119	7.754		[illegible]	
-4		.1285	.5006	.064327	[illegible]	60,006	7.762		4[illegible]30	
-5		.1270	.5018	.063729	4170	65,433	7.695		498,130	
-6		.1272	.5025	.063118	[illegible]	62,580	7.642		493,465	60,830 avc ; avc 7.847

DATA SHEET
MECHANICAL PROPERTIES

NML 725001 TEST Tensile

TITLE DATE 9-7-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
5-1AT-1	R.T.	.0515	.5018	.025843	5070	196,185	21.903		566,[illegible]	
-2		.0592	.5026	.029754	[illegible]	211,064	24.102		719,131	
-3		.0622	.5017	.031206	[illegible]150	199,077	22.444		[illegible]	
-4		.0599	.5012	.030022	6550	219,173	21.882		656,734	
-5		.0620	.5008	.031050	7240	233,172	22.254		649,909	
-6		.0609	.5006	.030487	6460	211,238	22.708		697,[illegible]	211,152 ave | 22.549 ave
5-1AT-7	110°F	.0580	.4997	.028982	[illegible]	224,622	29.181		916,042	
-8		.0579	.5012	.029011	[illegible]	225,714	24.421		723,661	
-9		.0542	.5023	.027225	[illegible]	229,936	26.931		733,193	226,757 ave | 26.511 ave
5-2AT-1	R.T.	.0573	.4999	.028594	1510	52,260	8.240		[illegible]	
-2		.0604	.5024	.030496	[illegible]	59,024	8.481		[illegible]	
-3		.0616	.5005	.030831	17[illegible]	57,734	8.766		270,27[illegible]	
-4		.0592	[illegible]	.029251	1810	61,878	8.741		255,69[illegible]	
-5		.0569	.5027	.028604	2080	72,717	9.863		[illegible]	
-6		.0580	.5019	.029110	1790	61,491	9.602		[illegible]503	60,851 ave || 8.949 ave

DATA SHEET

MECHANICAL PROPERTIES

NML 331626

TITLE

TEST Tensile

DATE 9-20-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
									(N X10	
[illegible]-IAT-1	R.T.	.0818	.5005	.040941	4890	119,440	24.945		102,12[illegible]	
-2		.0954	.5002	.047719	5780	121,126	23.142		110,4290	
-3		.0840	.4992	.0419[illegible]	49[illegible]0	117,569	24.741		103,746[illegible]	
-4		.0896	.5010	.0448[illegible]	4800	106,928	24.413		109,589	
-5		.0955	.5015	[illegible]	5170	128,524	24.092		115,385	
-6	↓	.0899	.4999	.044941	6060	134,303	23.085		103,74[illegible]	ave 121,456 24.070 ave
6-IAT-7	160°F	.0955	.5013	.0478[illegible]	5780	120,734	25.219		164,760	
-8		.0811	.5003	.040574	4380	107,951	26.606		93,385	
-9	↓	.0901	.5010	[illegible]	[illegible]	134,[illegible]14	29.888		123,499	ave 121,200 27.238 ave
[illegible]-2AT-1	R.T.	.0773	.5009	.038720	19[illegible]	49,587	11.450		44,335	
-2		.0780	.4990	.038922	[illegible]	49,073	11.238		43,942	
-3		.0736	.5010	.036[illegible]	135[illegible]	36,611	10.127		37,344	
-4		.0783	.5006	[illegible]	21[illegible]	54,596	11.866		46,512	
-5		.0812	.5005	[illegible]	[illegible]	41,584	10.363		32,759	(ind. value not averaged)
-6	↓	.0846	.4999	.042292	2190	51,783	10.955		46,332	ave 47,206 11.127 ave

DATA SHEET
MECHANICAL PROPERTIES

NML 331656   TEST Tensile

TITLE   J. SMITH   DATE

SPECI-MEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in^2	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi $\times 10^6$	P_y lbs.	y in/in	REMARKS	
1-1BT-1	RT	.0779	.9973	.077690	450	5,785	1.745		135,593		
-2		.0792	1.0008	.079263	478	6,031	1.634		129,4[illegible]		
-3		.0809	0.9998	.080[illegible]	360	4,456	1.397		112,853		
-4		.0805	1.0016	.0806[illegible]	376	4,663	1.436		115,756		
-5		.0827	1.0016	.082829	414	5,122	1.505		121,622		
-6		.0839	1.0008	.083969	468	5,573	1.643		137,931	5,292 ave	1.560 ave
1-1BT-7	160°F	.0819	0.9963	.081597	352.5	4,320	1.463		119,3[illegible]	[illegible]	
-8		.0815	1.0020	.081663	357.0	4,396	1.176		[illegible],000		
-9		.0829	0.9992	.082834	402.0	4,853	1.070		88,670	4523 ave	1.236 ave
2-1BT-1	RT	.0621	1.0005	.062131	—	—	—		—	[illegible]	
-2		.0613	0.9996	.061275	[illegible]	4,798	1.893		115,[illegible]		
-3		.0610	1.0004	.061024	196	3,212	1.393		121,6[illegible]		
-4		.0603	0.9996	.060276	164	2,721	2.081		125,436		
-5		.0594	1.0024	.059543	[illegible]	672	—		—	[illegible]	
-6		.0597	1.0005	.059430	80	1,346	2.339		[illegible]	2550 ave	2.074 ave
						[illegible]				3020	
2-1BT-7	160°F	.0574	1.0004	.057423	233.0	4,058	1.633		93,750		
-8		.0586	1.0024	.058741	296.5	5,048	1.697		99,[illegible]		
-9		.0585	1.0005	.058524	291.0	4,972	1.864		109,[illegible]	4,643 ave	1.731 ave

DATA SHEET

MECHANICAL PROPERTIES

NML 725001

TITLE

TEST Tensile

DATE 9-7-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
3-1BT-1	R.T.	.0740	0.9999	.073993	4[illegible]	6,352	1.915		141,732	
-2		.0718	1.0008	.07195[illegible]	4[illegible]	6,513	1.777		127,6[illegible]	
-3		[illegible]	1.0010	.0719[illegible]	[illegible]	3,557	1.767		127,2[illegible]	
-4		.0728	1.0005	.072836	[illegible]	4,174	1.753		127660	
-5		.0732	0.9995	.073163	364	4,975	1.885		137,?31	
-6	↓	[illegible]	1.0014	.072702	414	5,694	1827		132,8[illegible]	5,211 ave || 1.821 ave
3-1BT-7	[illegible]	[illegible]	1.0017	.072623	[illegible]	[illegible]	1.796		120435	
-8		.0725	1.0007	.072565	320	4,410	1.534		111,283	
-9	↓	.0743	1.00[illegible]	.074337	312	4,197	1.914		142,292	4,081 ave | 1.748 ave
5-1BT-1	RT	.0581	1.0026	.0582[illegible]	14[illegible]	2,541	1.212		70,[illegible]	
-2		.0563	0.9963	.05609[illegible]	116	2,062	1.340		95,1[illegible]7	
-3		.0575	1.0013	.057575	12[illegible]	2,119	1.587		[illegible],371	
-4		.0568	1.0004	.05682[illegible]	180	3,168	.999		113,565	
-5		.0555	1.0014	.0555[illegible]8	[illegible]	3,704	[illegible].005		111,[illegible]	
-6	↓	.0575	1.0020	.057615	236	4,096	[illegible].102		121,[illegible]	2,950 ave | 1.708 ave
5-1BT-7	160°F	.0568	1.0003	.056817	228.5	4,022	1.582		89,874	
-8		.0563	1.0018	.056401	196.0	3,475	1.438		81,081	
-9	↓	.0565	1.0017	.056596	195.0	3,445	1587		[illegible]	3,647 ave | 1.536 ave

DATA SHEET

MECHANICAL PROPERTIES

NML ______

TITLE ______

TEST Tensile

DATE 9-22-72

SPECIMEN NO.	TEST TEMP °F	DIMENSIONS THKNS in	WIDTH in	AREA in^2	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi $\times 10^6$	P_y lbs.	y in/in	REMARKS
4-1BF-1	R.T.	.1031	.9978	.10287	320	3,111	1.228		126,316	
-2		.1020	.9967	.10166	378	3,718	1.408		143,141	
-3		.1050	1.0012	.10513	448	4,261	1.436		150,943	
-4		.1047	1.0002	.10472	640	6,112	1.444		151,261	
-5		.1069	1.0011	.10702	626	5,849	1.241		132,841	
-6		.1067	1.0028	[illegible]	672	6,280	1.695		[illegible]	ave 4,889; ave 1.409
4-1BT-7	160°F	.1064	1.0028	.10670	547	5,127	1.492		159,151	
-8		.1070	1.0030	.10732	434	4,044	1.158		124,224	
-9		.1058	1.0027	.10609	324	3,054	1.291		134,831	ave 4,075; ave 1.307

DATA SHEET
MECHANICAL PROPERTIES

NML 331626 TEST Tensile

TITLE DATE 9-20-72

SPECIMEN NO	TEST TEMP °F	DIMENSIONS THKNS in	DIMENSIONS WIDTH in	DIMENSIONS AREA in²	ULT. LOAD lbs	ULT. STRESS psi	MODULUS psi × 10⁶	P_y lbs.	y in/in	REMARKS
6-1BT-1	R.T.	.0737	1.0008	.073759	346	4,691	1.542		113,744	600-Full .0005
-2		.0728	1.0014	.072902	74	1,015	—		—	
-3		.0727	1.0018	.072831	230.5	3,165	1.673		121,827	
-4		.0722	1.0014	.072301	267	3,693	1.964		142,012	
-5		.0715	1.0017	.071622	187.5	2,618	2.343		167,832	
-6		.0727	1.0016	.072816	265	3,649	4.478		326,087	ave 3,139 2.52 ave
6-1BT-7	150°F	.0717	1.0018	.071829	267.5	3,724	2.412		173,265	
-8		.0728	1.0026	.072989	263	3,603	2.222		162,162	
-9		.0715	1.0005	.071536	236	3,299	2.229		159,468	ave 3,542 2.288

* Not used in ave.